Metallurgy Department

Progress Report for the Period 1 January to 31 December 1981

Risø National Laboratory, Roskilde

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Risø National Laboratory, DK-4000 Roskilde, Denmark
July 1982

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METALLURGY DEPARTMENT PROGRESS REPORT FOR THE PERIOD 1 JANUARY TO 31 DECEMBER 1981

Abstract. The activities of the Metallurgy Department at Risø during 1981 are described. The work is presented in three chapters: General Materials Research, Technology and Materials Development, Fuel Elements. Furthermore, a survey is given of the department's participation in international collaboration and of its activities within education and training. A list (with abstracts) of publications and lectures by the staff during 1981 is included.

INIS-descriptors: FUEL ELEMENTS, METALLURGY, NONDESTRUCTIVE TESTING, RESEARCH PROGRAMS, RISOE NATIONAL LABORATORY.

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1. INTRODUCTION

Risø National Laboratory celebrates its 25th anniversary in 1982 and for this reason the present progress report is introduced by a short historical account of the development of Risø and the Metallurgy Department.

The Danish Atomic Energy Commission was set up in 1955 following the first Geneva Conference on the use of atomic energy for peaceful purposes. Its objects clause, which formed the guidelines for research at Risø for many years, spoke of "work for the promotion of the peaceful use of atomic energy in the interests of society". It emerged clearly from the conference in Geneva that atomic energy would find many applications within science and technology and that nuclear power stations provided the possibility to meet the demands of rising energy consumption.

Building work on the Risø site commenced in 1956. The Metallurgical Laboratories were not ready for occupation until 1961 although the first members of the metallurgical staff had already been employed in 1957 in the then Reactor Department.

The Laboratory and its research were structured to fulfil the following objectives:

I The Laboratory should carry out development work within areas of interest related to the construction of nuclear reactors.

II The laboratory should carry out both basic research and development work within areas of general metallurgical interest. The projects may either be formulated internally or may be proposed by research institutes in Denmark and abroad or by Danish industry.
Furthermore, the laboratory may undertake undergraduate and

graduate teaching and give courses of general metallurgical interest.

Meanwhile, the profitability of atomic energy was slow to demonstrate itself. In 1963 the Danish Technical and Scientific Research Council initiated a discussion into the question of a reduction in basic research with an extension of Risø's objectives to include technical and scientific subjects outside the field of atomic energy. This discussion, which at times became rather heated, did not lead to actual legislative changes but to a "peace treaty", from which may be quoted: "... the primary aim of the Atomic Energy Commission and Risø is to carry out industrially oriented research and not general basic research of the type carried out by university departments" (general basic research is understood to be that which seeks to provide new scientific knowledge and understanding; it differs from applied research in not being primarily directed to the solution of practical problems.) The argument surrounding Risø's activities flared up again some years later and in a statement which ended the debate, the Parliamentary Committee on the Atomic Energy Commission asserted (3rd October 1966): "It was finally agreed to request the Atomic Energy Commission to continue to maintain the existing capabilities for assisting industry, including that outside the nuclear sector."

In the mid-sixties it became clear that nuclear power was competitive with oil and coal and that the light- or heavy-water cooled reactor type would predominate. In 1964-65 Risø gave up work on an independent type of reactor - the organic-liquid cooled heavy water moderated reactor (DOR) and subsequently concentrated its research on the water cooled reactor. Despite the potential shown by atomic power, the Danish power producers were reluctant to take action. Then, as a result of the oil crisis in 1973, the decision was made to introduce nuclear power with the first power station planned for construction in 1980.

At more or less the same time the question of the safety of nuclear power became the subject of broad public debate. During the course of this discussion proposals for many alternative energy sources were brought to the fore. In order that these energy sources might be evaluated, research was needed. This research effort was mainly located in the research centres for atomic energy in a number of countries including Denmark, such that atomic energy laboratories were transformed into energy laboratories. As a consequence of this the Atomic Energy Commission was dissolved in 1976 and the broader aims of Risø's work were formulated thus: "... research, development and consultancy of relevance to the peaceful use and control of atomic energy" and "similar activities related to energy in general". Risø's long standing contract research agreements with public and private agencies were included at this time into Risø's objects clause (law regarding the provisions of energy policy, 28th April 1976).

During the years 1973 - 76, the power stations, Risø, the Danish authorities and Danish industry worked to create a technical basis for a political decision concerning nuclear energy in Denmark. In 1976 a government resolution postponed the final decision until a number of matters, including questions of safety and the disposal of radioactive waste, had been more accurately assessed; these assessments have not yet been concluded. Shortly after the postponement of the decision on nuclear energy many projects were started at Risø in the field of "alternative energy sources". At the same time, the tightening up of the financial situation resulted in a more intense involvement in contract research which has since come to dominate many of Risø's activities.

Many of the events described above have had a direct influence on the projects carried out in the Metallurgy Department. The general result has been one of balance where nuclear research and research into other energy forms each involve one third of the department's current resources. A significant part of this work is supported financially through public and private contracts. The remaining one third of the department's work com-

prises long term materials research. This sphere of activity which it has been possible to maintain throughout these upheavals, has been a prerequisite of the department's ability to adapt to the changing external conditions.

GENERAL MATERIALS RESEARCH

Additive strengthening

(In collaboration with the Department of Metallurgy and Materials Science, University of Cambridge).

Pine-grained polycrystals of pure copper and copper containing a dispersion of alumina particles were mechanically tested over a range of tensile strain. The Bauschinger effect was measured in order to determine the mean stress. Transmission electron microscopy was used to characterize the deformation substructure. The mechanical measurements and the structural observations were compared with the aim of analyzing the combined effect of the different strengthening mechanisms operating in the materials.

Patigue phenomena in copper

Patigue hardening and saturation were measured in single crystals of copper reinforced with tungsten fibres and in polycrystals of copper containing alumina particles. The cyclic stress-strain (CSS) curve of high-purity texture-free copper polycrystals was found to depend on the mean grain-size in the range from ~ 25 μm to ~ 380 μm. In coarse-grained polycrystals the saturation stress may be controlled entirely by bulk persistent slip (PSB model); but the observed grain-size dependence and electron microscopy suggest that dislocation structures harder than persistent slip bands are activated in more fine-grained material.

In collaboration with the Cavendish Laboratory, University of Cambridge, the intergranular stresses implied by the Sachs model were studied theoretically using a self-consistent ap-

proach. The Sachs model accounts semi-quantitatively for the experimentally observed grain-size independent component of the saturation stress. A similar analysis showed that the Taylor model cannot account for the data if the deformation occurs by bulk persistent slip.

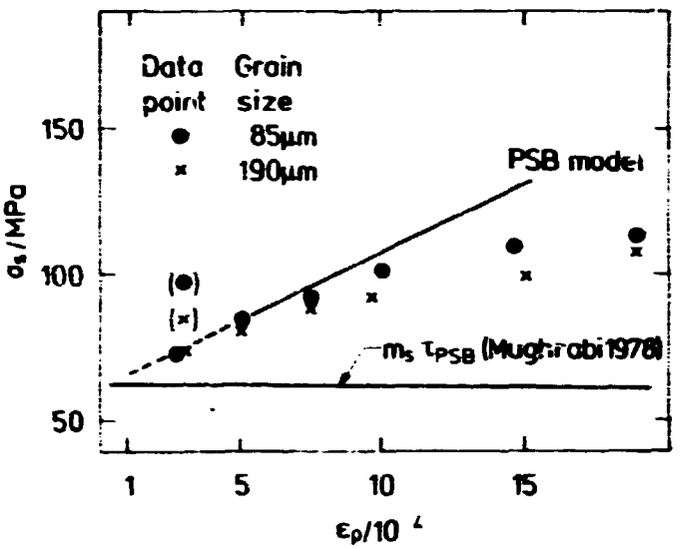

Fig. 1. Grain-size dependence of the CSS curve of polycrystalline copper. (a) The PSB model accounts for the CSS curve of coarse-grained copper at low strain amplitudes but not for its grain-size dependence. (b) cell and vein structures separated by a grain-boundary in fine-grained copper, the cells are modified at the grain boundary (grain-size ~ 25 µm, plastic strain amplitude = 10^{-3}).

Creep in fcc metals

In its traditional form, the dislocation network recovery model for creep is unable to yield stress exponents for steady-state creep higher than approximately 3, which is lower than the experimental stress exponents. Likewise it cannot account for the way recovery proceeds during an annealing after a creep deformation. In view of this, the network recovery model was modified by the introduction of more detailed dislocation interaction mechanisms. The modified model yields realistic stress exponents and offers an explanation of the initial fast recovery during annealing after creep.

Creep experiments were initiated on Cu dispersion-hardened with Al_2O_3, and the developed dislocation structures were studied by transmission electron microscopy.

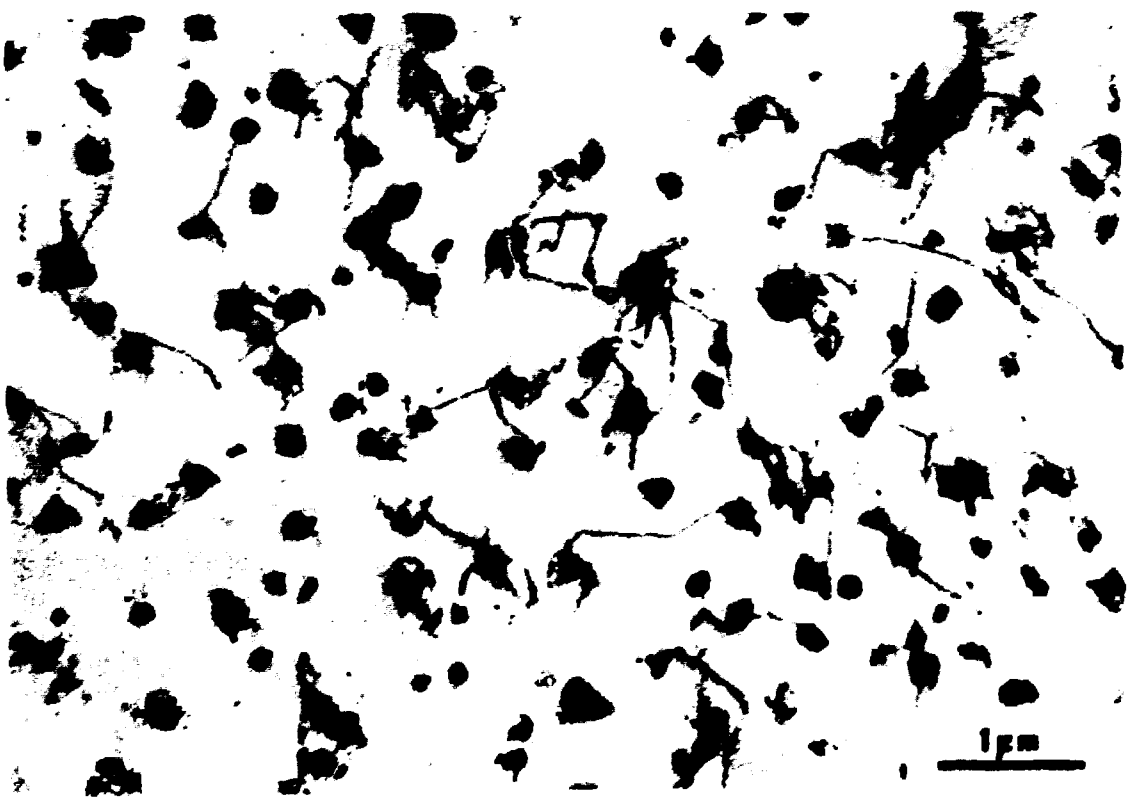

Fig. 2. Dislocation structure in a Cu-Al_2O_3 specimen creep deformed at 70 MPa and 400 °C.

Radiation damage in stainless steel

(In collaboration with the Metallurgy Division, AERE, Harwell).

The study of the combined effects of silicon and implanted helium on void nucleation and growth in a high purity austenitic stainless steel was continued. Specimens containing 0.25 to 2.0 wt. % silicon and 10 atomic ppm of pre-injected helium were irradiated at temperatures in the range 400-750 °C in the Harwell high voltage electron microscope (HVEM). The increase in void density due to helium was found to be significantly lower in the high silicon alloys than in the base and the low silicon alloys. The presence of pre-injected helium reduces the duration of continuous nucleation in the high silicon alloys. Some preliminary irradiation experiments were carried out at temperatures in the range 600-750 °C on cold-worked specimens containing 0, 1.0, and 2.0 % silicon. Cold-work was found to increase the void density at all irradiation temperatures used. At higher irradiation temperatures the 2.0 % silicon alloy was found to swell at a significantly lower rate in the cold-worked condition than in the solution treated condition (i.e. without cold-work).

Irradiation of high purity aluminium with 600 MeV protons and 225 MeV electrons

In collaboration with EIR/SIN (Switzerland) annealed samples of high purity aluminium (99.99 %) were irradiated with 600 MeV protons using the PIREX facility at the Swiss Institute for Nuclear Research (SIN). The irradiation experiments were carried out at 120 and 160 °C; the beam current density used in the experiments gave a damage rate of 3.5×10^{-6} dpa s^{-1} for aluminium. During 600 MeV proton irradiation the rate of helium generation in aluminium is 125 atomic ppm per dpa which is about four times higher than expected in the first wall of a fusion reactor. The irradiated specimens have been examined in a 100 kV electron microscope.

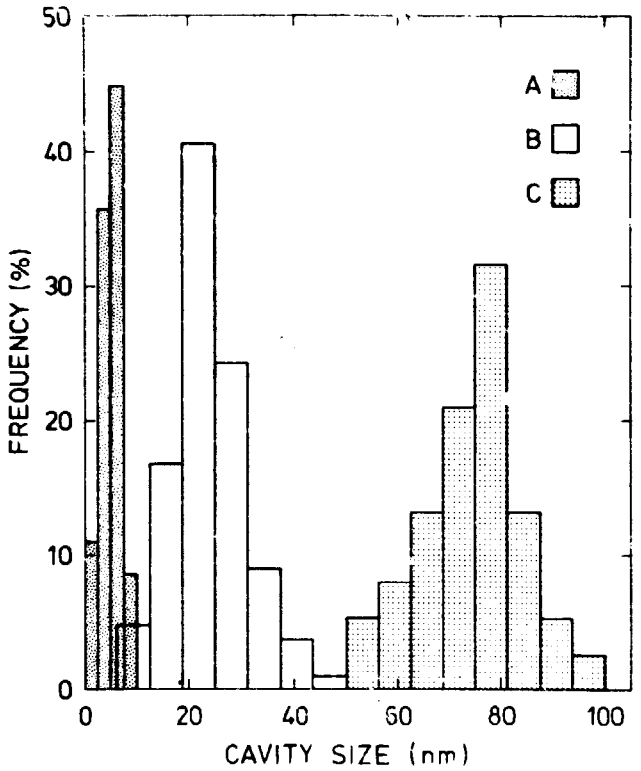

Fig. 3. Cavity size-distribution in aluminium irradiated with 600 MeV protons to a dose of 2 dpa at 120 °C. A - at grain boundaries, B and C - away from grain boundaries. In order that they can be shown on the same scale distributions B and C have been separated so that each of them add up to 100%. The actual number of cavities in distribution C is only 7% of the total number in the area in question.

TEM examinations showed the presence of cavities in specimens irradiated to all three doses (i.e. 0.2, 0.6 and 2 dpa). In specimens irradiated at 120° C the spatial distribution of cavities was found to be very heterogeneous: the cavities were found to be present only in a relatively narrow band along grain boundaries and the interior was almost free of visible cavities. At 2 dpa cavities with three different size distributions were observed; the smallest cavities were at the grain boundaries whereas a dual-size distribution existed in the band of cavities at some distance away from the grain boundaries. The large cavities of the dual size distribution are thought to be nucleated by the residual gases whereas the small ones are nucleated by helium atoms generated during irradiation.

In collaboration with Kharkov Physical Technical Institute (KPTI) samples of the same high purity aluminium were irradiated with a pulsating beam of 225 MeV electrons in the linear electron accelerator LUE-300 at KPTI. The frequency of the pulses was 50 Hz and the pulse length was 1 μs. The aluminium samples were placed in an assembly consisting of 8 to 10 aluminium samples separated by pieces of nickel. The damage rate was about 1×10^{-8} dpa/sec at the beginning of the assembly and $3 \cdot 10^{-8}$ dpa/sec at a depth of one radiation length. The maximum dose was around 0.1 dpa. The helium production rate increases from almost zero at the beginning of the assembly to about 10 atomic ppm per dpa at a depth of one radiation length.

The irradiated aluminium was examined by transmission electron microscopy. The specimens contained cavities in the size range 5 to 40 nm. The cavities were unevenly distributed, sometimes occurring in groups, and the number density was rather low.

Irradiation of high purity aluminium with neutrons

Specimens of high purity aluminium (the same aluminium as used in the high energy proton and electron experiments) were irradiated at 90 and 120 °C in the DR-3 reactor at Risø to doses of 2×10^{17}, 1×10^{18}, 5×10^{18}, 1×10^{19} and 1×10^{20} n/cm^2. The rate of helium production during irradiation is likely to be of the order of 1 atomic ppm per dpa which is significantly lower than the helium generation rate in the high energy proton ($\approx$ 125 atomic ppm per dpa) and electron ($\approx$ 10 atomic ppm per dpa) irradiations. The results of the neutron irradiation experiments would therefore supplement the study of the effect of gas production rate on void nucleation and growth.

Voids were observed in aluminium specimens irradiated to all doses down to and including 1×10^{18} n/cm^2. Both the size and number density of voids are seen to increase with dose.

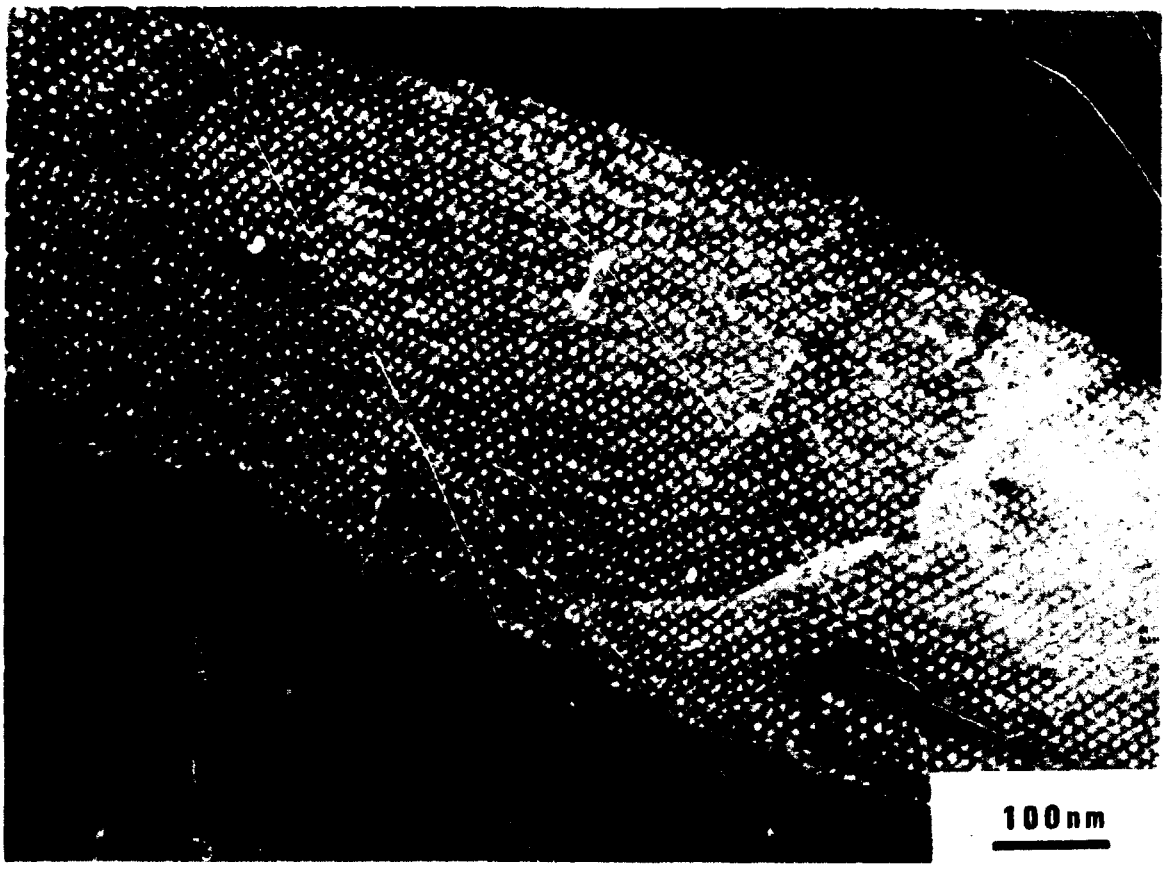

Fig. 4. Low angle grain boundary in cold-worked and annealed high-purity aluminium irradiated with fast neutrons at 120 °C to a dose level of 1×10^{20} n/cm^2. A void can be seen in the lower left hand corner near a matrix dislocation. No voids are observed near similar dislocations in the low angle boundary.

Computer investigation of radiation damage

The experimental work on radiation damage is supported by computer investigation of various associated processes. The recombination cross section for interstitials and vacancies was calculated as a function of vacancy concentration using atomistic simulation of the migration of point defects. There is a surprisingly small difference between the results obtained by simulation on atomic level and the results of continuum calculations.

In some irradiated materials (cold-worked materials for instance) the dislocations are not uniformly distributed as assumed in standard rate theory. A computer code was developed to calculate the swelling rate in such materials (cooperation with KPTI Kharkov, USSR). The results demonstrate the decisive influence of the dislocation distribution.

The effect of helium generation rate at a given damage rate and irradiation temperature and helium concentration on void density was calculated with use of the "homogeneous" nucleation theory based on agglomeration of vacancy-gas atom clusters. The maximum void density was found to vary approximately as the square root of the helium generation rate and the helium concentration. The predicted effect of helium concentration on the void density was found to be in reasonable agreement with experimental results.

Neutron diffraction investigation of recrystallization kinetics

(In collaboration with Physics Dept., Risø).

Recrystallization kinetics were investigated by on-line neutron-diffraction texture measurements. Two major improvements were implemented in the texture recording set-up: a position-sensitive detector which simultaneously registers pole densities in 19 points on a great circle in the pole figure and a computer-controlled Euler cradle which can give the specimen any desired orientation. With this set-up we can now record a pole figure in 14 minutes, and there is scope for further reduction of the time needed to record a pole figure. A new hot stage, in which heating takes place by a stream of hot air, has improved the temperature control. For moderate temperatures (~ 200 ^{o}C) it takes 1/2 minute to reach temperature equilibrium (starting at room temperature) and the temperature is then kept within ± 0.1 ^{o}C.

The kinetics of the recrystallization of heavily-rolled fine-grained and coarse-grained copper was investigated. These two

materials (of the same chemical composition) have clearly different recrystallization textures and recrystallization rates, but it was not possible to detect any qualitative difference in the kinetic behaviour.

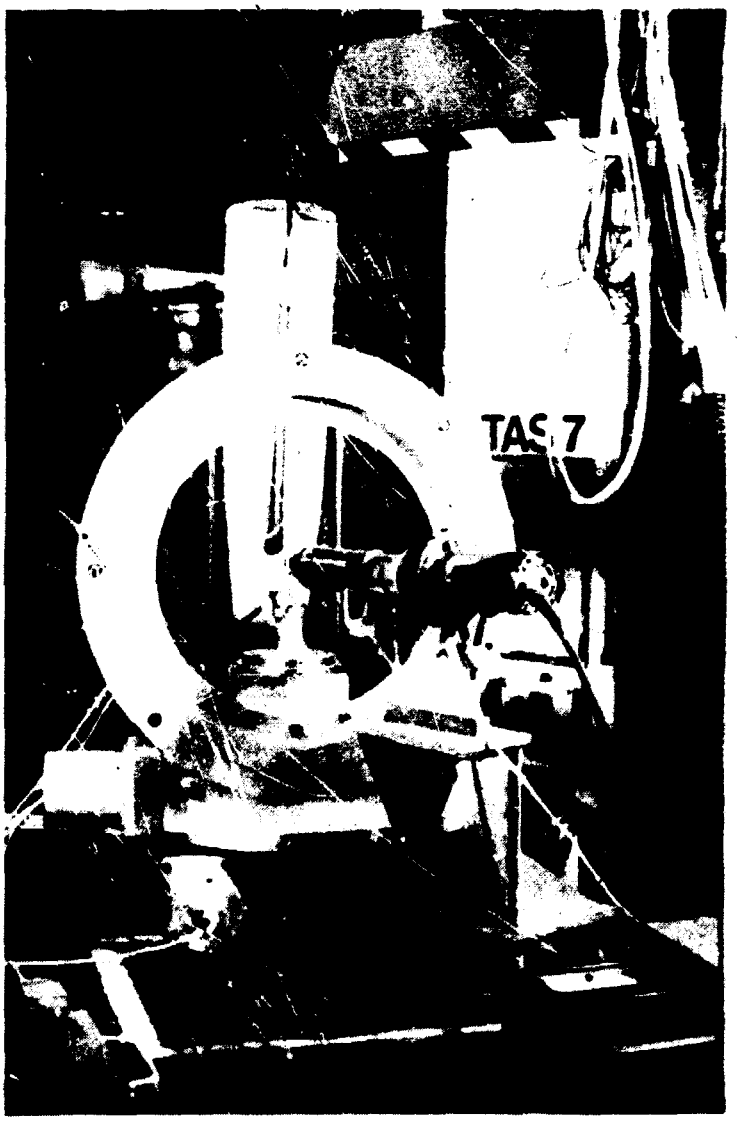

Fig. 5. Neutron texture goniometer. The specimen is mounted in an automatically controlled Euler cradle. The position sensitive detector is seen behind the Euler cradle, and the hot-air blower is seen in the foreground.

Recrystallization and grain growth in particle containing materials.

(In collaboration with the Department of Metallurgy and Materials Science, University of Cambridge).

The recovery, recrystallization and grain growth of metals containing a dispersion of small particles (diameter < 0.1 μm) was studied with special emphasis on aluminium-alumina alloys. The dislocation mechanisms involved in subgrain growth were examined by transmission electron microscopy and it was observed that the retardation of recovery and recrystallization caused by the presence of small particles involves pinning of both low and high angle boundaries. Grain growth after recrystallization was studied by quantitative light microscopy.

Microstructures in cold-worked polycrystalline aluminium

(In collaboration with the Danish Academy of Engineering).

The microstructures produced by cold rolling pure aluminium (99.998 %) and aluminium of commercial purity was studied by transmission electron microscopy. Studies of the bulk behaviour were supplemented by replica examination in the electron microscope of surface displacements during deformation. These studies form the basis for future work on deformation mechanisms and recrystallization behaviour of aluminium alloys.

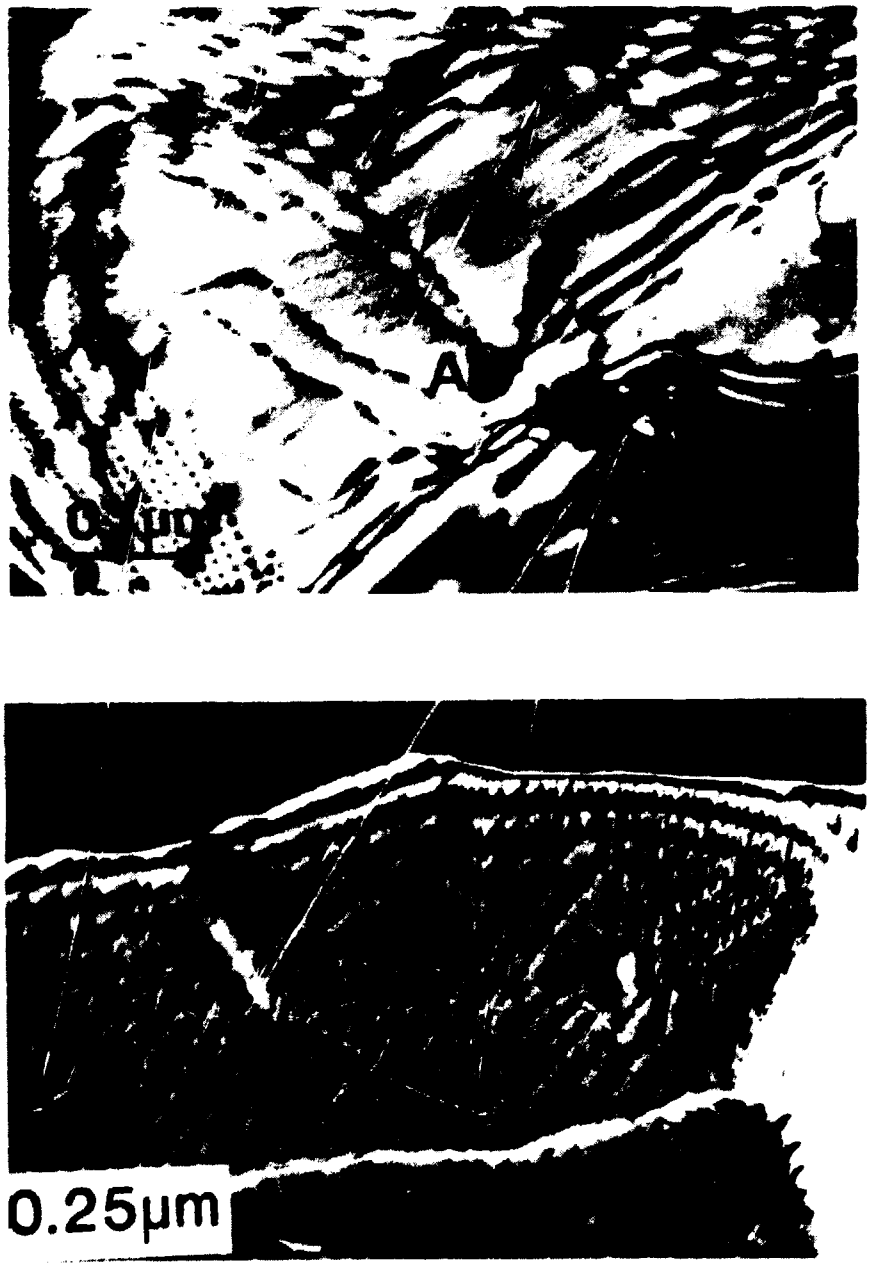

Fig. 6. (a) Dislocations (arrowed) pinned at an alumina particle (A) while in the process of migration within the plane of a low angle grain boundary. (b) A centred dark field image showing the pinning of dislocations at particles. Aluminium containing an 6×10^{-4} volume fraction of alumina, cold worked 50% and annealed for 20 min at 300 °C.

TECHNOLOGY AND MATERIALS DEVELOPMENT

Irradiation embrittlement of reactor pressure vessel steels

A screw-driven testing machine was designed and built for elasto-plastic fracture testing of side-grooved specimens in slow bending according to the multispecimen J-resistance curve procedure. Specimens were irradiated to a maximum dose of 5×10^{20} n/cm^2 at 290 °C.

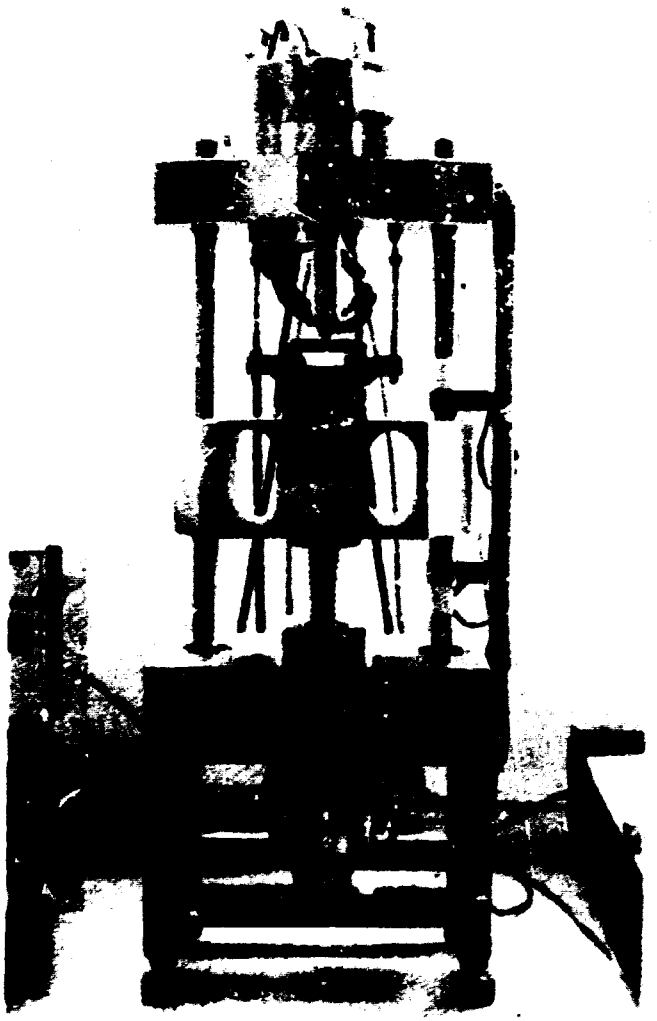

Fig. 7. Pre-fatigued three-point bend specimen mounted in a screw driven testing machine. The load and the displacement of the load point are recorded. Overall machine height is about 750 mm.

Fig. 8. Brittle intermetallic phase in the middle of a brazed gap. It is seen that the brittle interphase disappears when the gap becomes sufficiently thin.

Brazing and soldering

An investigation was made of the brazing of stainless steels using Ni-Cr filler metals containing Si, B or P as temperature depressants. The strength of the brazed joints may be reduced by brittle intermetallics. The maximum gap width free of these intermetallics was measured as a function of heat treatment of the brazed joint for ASTM 304 stainless steel brazed with BNi-1 and BNi-2.

Contract work was continued on industrial applications of dip-brazing, vacuum brazing and ultrasonic soldering of aluminium as well as vacuum brazing of stainless steels and nickel alloys.

Fabrication technology of composite materials

The filament winding machine is now capable of fabricating components of shapes that are cylindrical, conical or combinations of these. The cross-sections of the components can be circular or any other convex geometry. The machine can produce (nearly) all combinations of fibre orientations, from axial fibres to circumferential fibres. The winding process is controlled by a computer. This allows automated winding with predetermined fibre orientations on a mandrel of known geometry. Furthermore, the computer can store information about a manual winding operation and later reproduce the winding. In all cases, the computer ensures a well-defined and reproducible fabrication. The winding machine is at present arranged to fabricate components of glass and carbon fibres in polymeric matrices.

The autoclave was fitted with automatic recording of fabrication parameters, e.g. temperature and pressure. The effect of the

Fig. 9. Computer controlled filament winding machine.

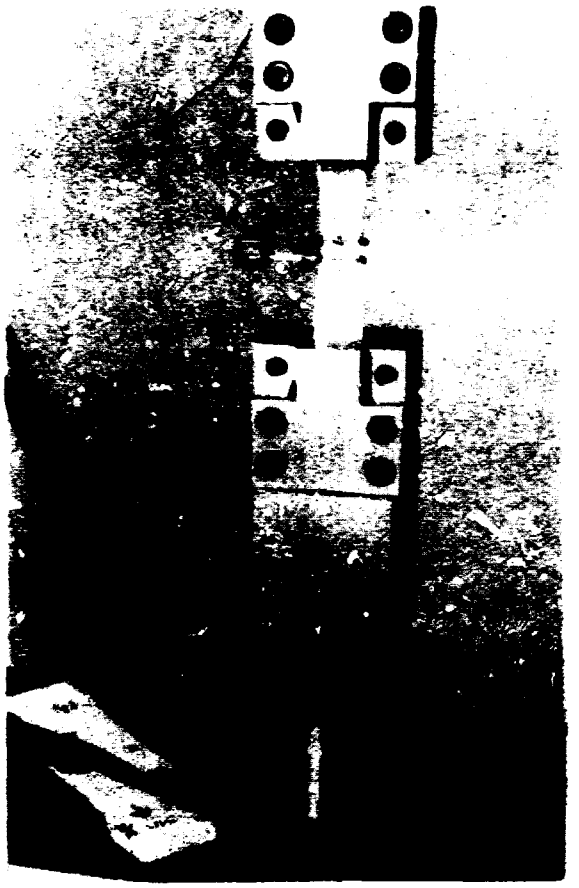

Fig. 10. Fatigue testing of composite materials. The specimen is polyester reinforced with long parallel glas fibres.

distribution of these parameters on the curing process was studied. The autoclave is being used for the fabrication of flat laminates of glass/epoxy and carbon/epoxy.

Methods of testing composite materials

A study was carried out to investigate the suitability of different testing methods to determine the compressive strength of composites. In particular a comparison between a testing method recommended by ASTM and a simpler method was made. Testing to determine flexural properties of sandwich-type composite components was also made. A considerable effort was spent in solving the problems related to fatigue testing of thick laminates

in the tension-tension mode. Various specimen designs were tested and the fracture modes were studied.

Mechanical properties of composite materials

Work on fatigue is carried out with a two-fold purpose: to explain the basic damage mechanisms under fatigue and to develop models for predicting the fatigue life of composite structures. A study of the damage mechanisms led to the development of diagrams on strain-life axes that show regions in which different mechanisms dominate the fatigue behaviour. An important outcome of these diagrams is the clarification of the limits of the fatigue performance of composite materials. Measurements were made of changes in the stiffness properties induced by fatigue. Attempts to relate the stiffness changes to the underlying fatigue damage mechanisms continue.

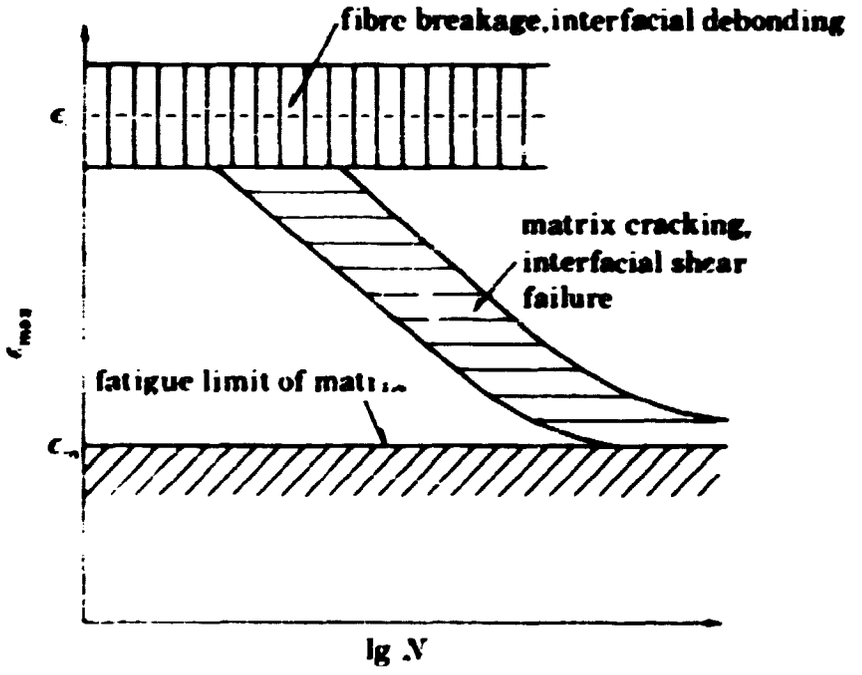

Fig. 11. Fatigue-life diagram for unidirectional composites loaded parallel to the fibres.

The compressive strength was studied to clarify the influence of the factors that limit the compressive strength, e.g. microbuckling and kinking of fibres.

Machining of carbon-fibre-reinforced plastics

A model was developed for machining of unidirectional fibre composites in a direction parallel to the fibres. The model expresses the cutting force parallel to the fibres in terms of the stiffness and strength of the composite and the compliance of the machine system. Machining of discs of cross-ply laminates showed that the surface quality depends on the angle between the cutting direction and the fibres.

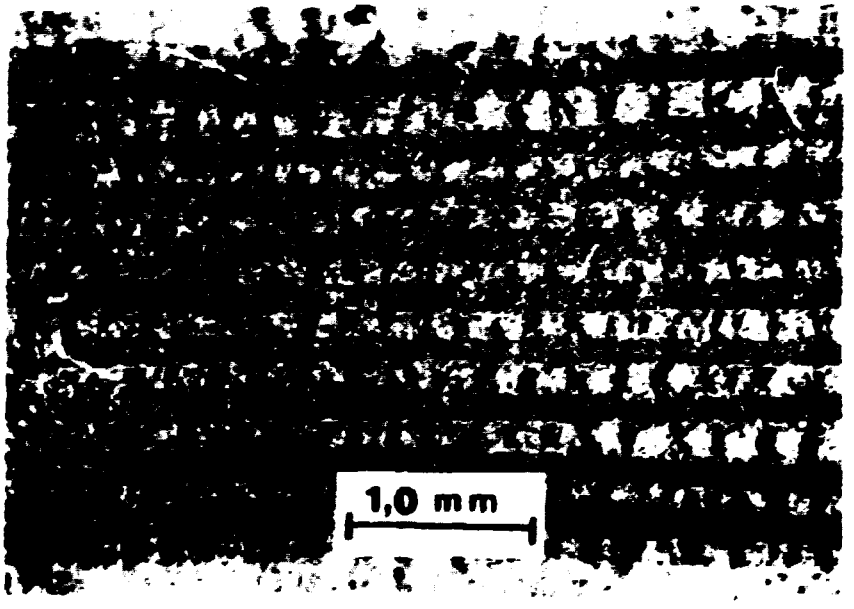

Fig. 12. Machined surface of epoxy reinforced with long parallel carbon fibres.

Laminate analysis and design of composite structures

The development of simplified analyses of laminates towards designing them for given requirements of strength and stiffness properties was continued. Studies were made concerning materials

selection, design and fabrication of small wingblades (5-10 meters in length) of fibre composite materials.

Metal-hydrogen systems

Magnesium powders produced by different methods, including those used in large scale manufacturing, were tested for reaction with hydrogen. The reaction rate in the first absorption-desorption cycle seemed to depend upon the specific surface area. After a few cycles, however, only small differences were found in absorption kinetics or maximum hydrogen uptake. Differences in the desorption kinetics were also small, but in some powders about 10 % of the hydrogen was not released at a pressure of 150 kPa.

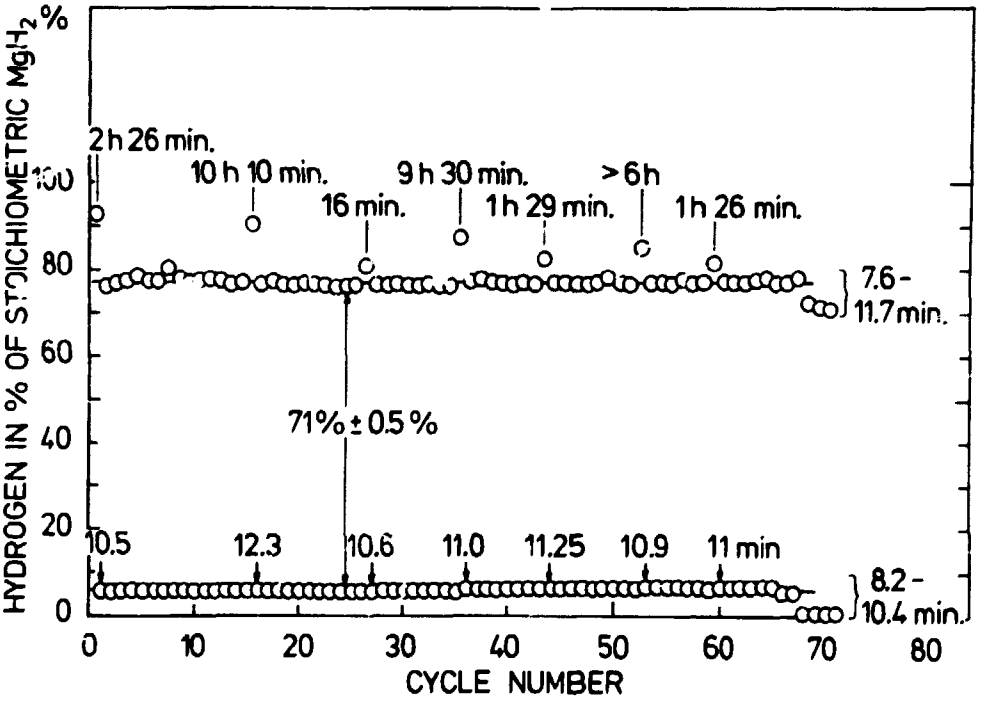

Fig. 13. Behaviour of the magnesium-hydrogen system in a cyclic absorption-desorption experiment.

The behaviour of the Mg-H system over many cycles of absorption-desorption was studied in preliminary tests. A fully automatic cycling facility was built for long term testing.

Solid electrolytes for lithium batteries

(In collaboration with the Physics Department at Risø).

The development and characterisation of ionically conducting solids for use in rechargeable lithium batteries were continued. Two new techniques were used to supplement computer controlled conductivity measurements on new materials: cyclic voltametry was used to monitor the electrochemical stability range of possible battery materials and, secondly, the thermal stability of new solid electrolytes was determined in the temperature interval from ~ - 50 °C to ~ + 800 °C by differential scanning calorimetry (DSC).

Considerable progress was made in fabrication of composite LiI-Al_2O_3 electrolytes. Milling-, pressing-, and heat treatment conditions were established, which yield materials with a conductivity better than those previously reported (part of an Anglo-Danish EEC sponsored programme).

New possible lithium ion conducting compounds are being synthesized in a project sponsored by the Danish Ministry of Energy. Neutron and x-ray scattering investigations of $LiI \cdot D_2O$, $LiBiO_2$, and Li-sulphate systems were continued with the purpose of studying the influence of the structural properties on the Li-ion conduction mechanisms.

A theoretical model for predicting the transport properties of highly doped and defective solids was put forward. The model was used to analyze the dependence of the ionic conductivity of doped cubic oxides.

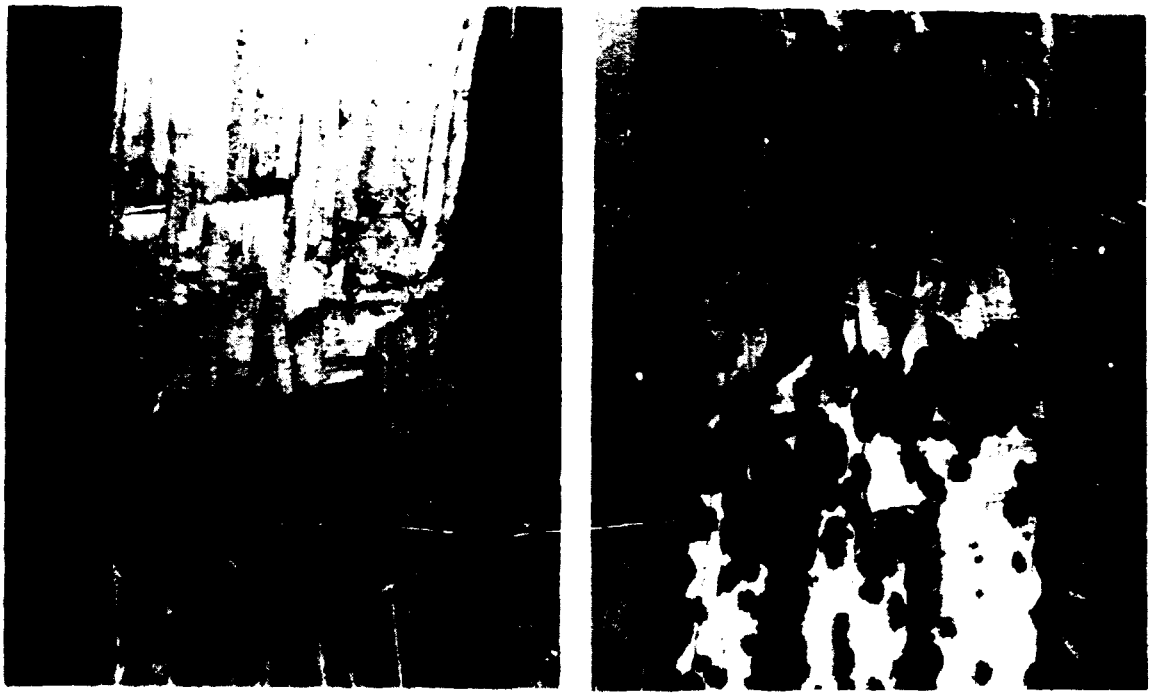

Fig. 14 Formation of surface layers of lithium-nitride (Li_3N) on lithium metal in nitrogen. Left, clean lithium surface. Right, nitrided lithium surface.

Lithium electrodes for non-reversible batteries

(In collaboration with A/S Hellesens).

Development and testing of lithium anodes for non-reversible lithium-thionylchloride batteries was started (financially supported by the Danish Ministry of Energy). The primary aim is to examine the phenomena of "delayed action", commonly observed in batteries of this type. Work was therefore concentrated on developing methods for characterising surface layers formed on the lithium anodes with respect to chemical composition, microstructure and electrochemical properties.

Lithium-alloy anodes for reversible batteries

(In collaboration with Imperial College, London)

Development and testing of lithium alloys for potential use as anodes in reversible all solid state batteries was started (financially supported by EEC). The fabrication of lithium-boron and lithium-aluminium was studied by differential thermal analysis. Electrochemical cells for testing of the alloys were constructed.

Erosion-corrosion of steel

Concentrated hydrogen carbonate solutions are strongly passivating against unalloyed and low-alloy steels, giving a very low corrosion rate at temperatures up to 250 °C. Between 250 and 300 °C, the protectiveness of the oxide film decreases.

In rapidly flowing slurries, a mechanical action is added to the electrochemical attack, and even under strongly passivating conditions a nonzero loss rate must be expected. However, at 200 °C the oxide film still has sufficiently good mechanical properties to resist erosion from a slurry flowing up to some metres per second.

The sensitivity of the passive layer on steels in hydrogen carbonate solutions to attack by fluoride and chloride ions has been investigated under atmospheric conditions up to 90 °C. Fluoride concentrations up to saturation and chloride up to at least 0.1 % do not lead to pitting or other degradation of the passive layer.

FUEL ELEMENTS

The Danish fuel elements in the Kahl and Halden reactors condesign and manufacturing processes. The Kahl elements reached their design burn-up and were discharged.

The irradiation of UO_2-Zr fuel pins in the DR 3 reactor at Risø includes standard BWR and PWR type tests irradiated to very high burn-ups. Special tests such as "bump tests" are also being made within the Risø Fission Gas Project.

Additional information on fuel performance becomes available as a result of international collaboration arrangements, i.e., the OECD Halden Reactor Project (Norway), the "Demo-Ramp II" (BWR fuel) and the "Super-Ramp" (PWR and BWR fuel) projects at Studsvik (Sweden), Battelle's "High Burnup Effects Program", the information exchange with the NRC (USA), and the EEC sponsored activities (Brussels) relating to Pu recycling in LWRs.

Danish fuel element irradiations in the Kahl and Halden reactors

The four Danish fuel elements in the German BWR power reactor went on power for the first time in 1975. Irradiation was continued and these elements have now achieved their design burn-up and were discharged at 19,700 MWD/tU. Two short tests fuel pins, manufactured from the same UO_2 and Zr materials as the Kahl fuel pins, have now reached a burn-up of 50,000 MWD/tU in the DR 3 reactor.

Irradiation of the four test fuel elements in the Halden reactor (Norway) was continued. They have now reached the following estimated burn-ups (average assembly, after correction for fuel depletion):

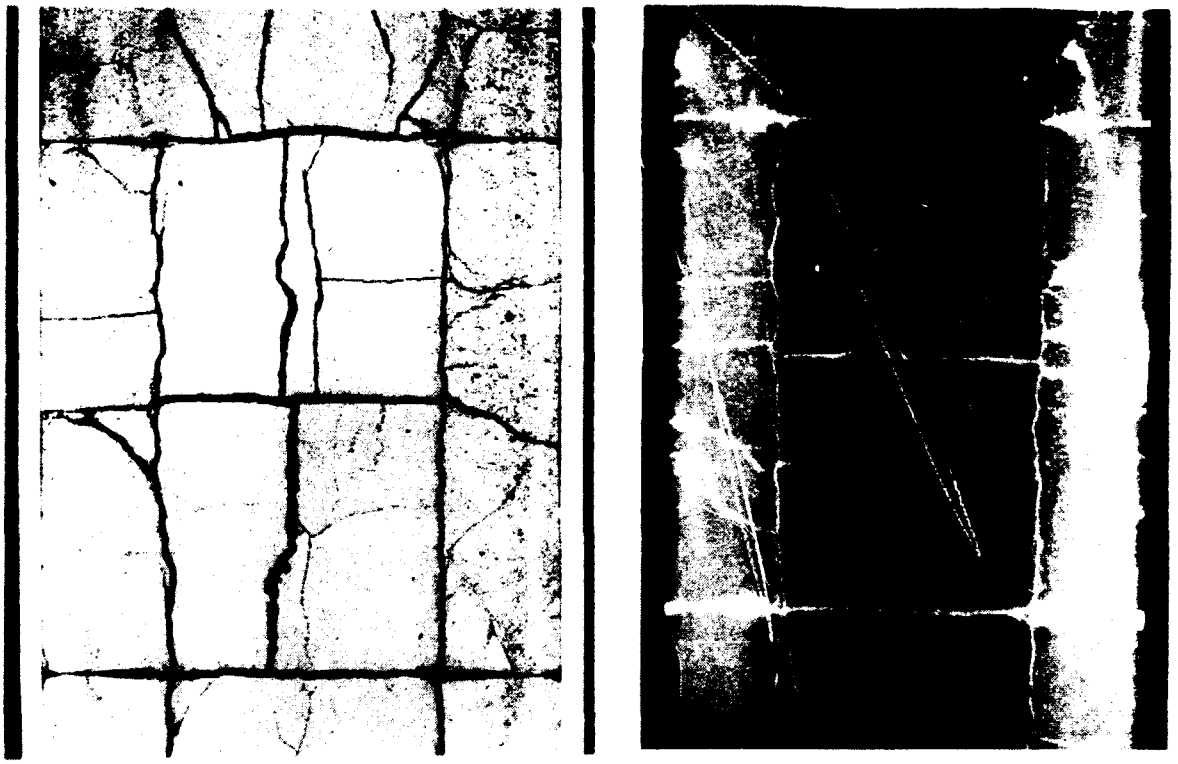

Fig. 15. Longitudinal cross-section of high-burnup, transient tested UO_2-Zr fuel. Left, as polished. Right, beta/gamma autoradiograph.

IFA No.	161	165	201	202
MWD/tU	44,000	41,900	39,700	35,100

The maximum local burn-up of 53,000 MWD/tU was achieved with IFA 161. This assembly was discharged in preparation for a new Risø project to study fission gas release in transients at high burn-up (see below).

UO_2-Zr irradiations at Risø

In the test fuel irradiation programme at the DR 3 reactor, standard fuel pins have reached max. burn-up levels of 68,500 and 55,000 MWD/tU for BWR and PWR type fuel, respectively.

The Risø fission gas project

The objective of this project was to provide well-characterized experimental data on fission gas release and other aspects of the high-burn-up performance of water reactor fuel. The project was sponsored internationally by fuel suppliers, electric utilities and nuclear safety and research organizations. The project was completed according to schedule by the end of 1981.

UO_2-Zr fuel pins were previously irradiated to peak pellet burn-ups exceeding 35,000 MWD/t UO_2. Most of these fuel pins were subjected to a short re-irradiation ("bump test") in the DR 3 reactor at Risø, in order to simulate postulated power increases late in life for power reactor fuel. A gamma spectrometry technique developed at Risø permitted a non-destructive assessment of the fission gas content of a fuel pin, thus enabling repeated bump testing prior to the ultimate destructive examinations which included the following:

Technique	Observations
Puncturing	Fission gas analysis of whole pin
Retained gas measurement	Fission gas content of pellet size samples
Electron microprobe analysis	Diametral Xe og Cs distribution
Micro gamma scanning	Diametral Zr-95 and Cs-137 distribution
Ceramography with quantitative image analysis	Fuel structure, especially pore size distribution and grain size
Burn-up and heavy isotope analysis	Burn-up; basis for calc. of fission gas generated

The above hot-cell examinations were performed at Risø, except for electron microprobe analysis which was carried out at the Transuranium Institute of Karlsruhe (F.R. Germany).

Some of the experimental observations are listed below:

1. The integral pin fission gas release resulting from the bump testing was in the range 0-16 %. These bump releases were close to zero at bump termiral level (BTL) less than 400 W/cm (peak pellet) and they increased with BTL above 400 W/cm.
2. The axial power shape during the bump testing differed from the base-irradiation shape because the DR 3 Reactor has a smaller core height than the Halden Reactor. As a result, each bump test was in fact a whole series of experiments with a range of BTLs. This was exploited by means of retained gas measurements on pellet size samples.
3. The diametral Cs-137 scans showed various degrees of depletion in the hotter, central pellet part, depending on the local BTL. Local Cs releases could be calculated from these scans. The local fission gas and Cs releases seemed to correlate with local BTL in a similar manner.
4. Extensive ceramographic examinations of base irradiated and bump tested fuel samples as well as unirradiated archive pellets were carried out, and pore structures were evaluated by quantitative image analysis. The results of these examinations further characterized and supported the fission gas release observations and gave information regarding swelling at high burn-up.

Transient fission gas release in high-burn-up UO_2-Zr fuel

The most important test parameter in the above Risø Fission Gas Project was the transient power level, with a hold time of 24 hours in almost all of the tests. There is, however, interest in data on the fission gas release of high-burn-up fuel as a function of hold time and there are very few data available.

On this background, Risø is making preparations for a new project to study the kinetics of fission gas release at high burn-up. This project will be internationally sponsored similar to the previous project. The test fuel will come partly from one of the Danish Halden assemblies (IFA 161) and partly from a BWR power reactor. The fuel will be refabricated in the Risø hot cells into shorter test pins, most of which will be provided with pressure transducers. These test pins will then be subjected to typical power transients in the DR 3 reactor and the changes in the internal pin pressure will be monitored continuously. There will also be the possibility of testing short, unopened fuel segments previously irradiated to significant burn-up levels. After the transient test, the fuel will be examined in detail in the hot cells.

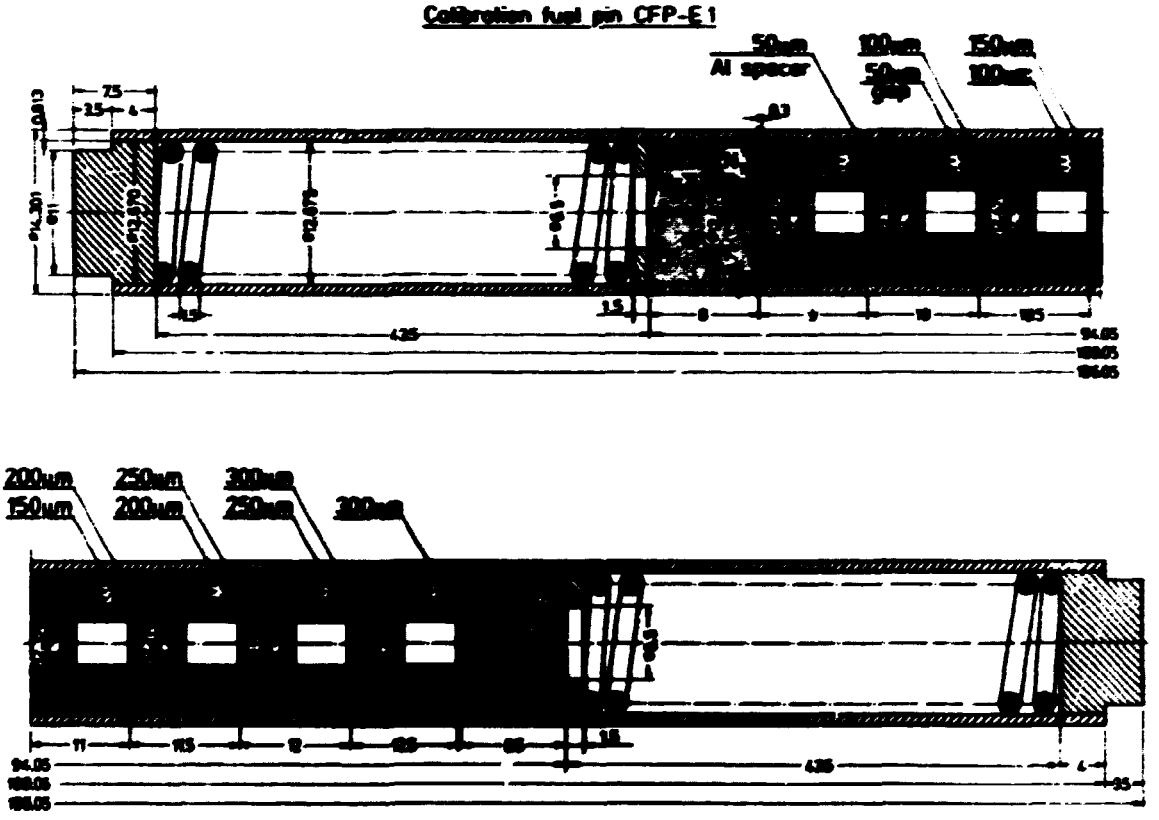

Fig. 16. Calibration fuel pins for testing the accuracy of dimensional measurements.

Neutron radiography

Special indicators were fabricated at Risø for the Euratom Radiography Working Group. They will be used by all members of the Group to test the neutron beam components and the quality of the radiographic image under a special test programme. The accuracy of dimensional measurements will be tested by calibration fuel pins designed and produced at Risø.

PARTICIPATION IN INTERNATIONAL COLLABORATION

The department is engaged in the following types of international collaboration: joint technical projects, committee work, reception of research fellows, and technical and scientific meetings. The cooperation programme on irradiation damage between the department and the Kharkov Physical-Technical Institute was continued.

The department was represented on the following committees:

The Information Exchange Group under the European Space Agency on Carbon Fibre Reinforced Plastics,

The Halden Programme Group,

The IAEA International Working Groups on "Reliability of Reactor Pressure Components" and "Water Reactor Fuel Performance and Technology",

The Over-Ramp, Super-Ramp and Demo-Ramp Project Committees,
The Project Committee on the Battelle HBEP-Programme.
The OECD/EEC Nuclear Agency's Committee on the Safety of Nuclear Installations (NEA-CSNI) Working Group on Safety Aspects of Steel Components in Nuclear Installations,

The COST 501 Committee on Materials for Energy Conversion using Fossile Fuels,

The EEC Advisory Committees for Programme Management: "Plutonium and Transuranium Elements" and "High Temperature Materials",

The European Coal and Steel Community,

Executive Committee No. 5: Failure Mechanisms and Design,

The Euratom Neutron Radiography Working Group,

The Council of the International Confederation of Thermal Analysis,

The Nordic Committee for Thermal Analysis,

and in the Technical Commission of the International Institute of Welding, Commission I, "Gas Welding and Allied Processes", Subcommission A, "Brazing and Surfacing".

EDUCATION AND TRAINING

N. Hansen and K. Rørbo gave regular lectures on materials science to students at the Danish Academy of Engineering. O. Toft Sørensen, B. Vigeholm, A.S. Pedersen and B.N. Singh lectured on physical materials science to students at the Technical University of Denmark. N. Hansen, T. Leffers and H. Lilholt acted as external examiners at examinations for the Technical University of Denmark, and O. Toft Sørensen acted as external examiner at examinations for the Technical University of Norway, Trondheim.

Two scholarship holders from Egypt worked in the Department on projects in the field of non-destructive testing, and in the field of materials testing, respectively.

One scholarship holder from India worked in the Department on projects in the field of fracture mechanics study of irradiated pressure vessel steels.

Post-graduate projects

Three post-graduate students from the Technical University of Denmark worked in the department on the following projects in preparation for their licentiate (Ph.D.) theses:

A. Koplev:	Machining of fibre-reinforced plastics
J. Vestergaard Sørensen:	Thermomechanical forming processes
D. Juul Jensen:	Investigation of recrystallization kinetics by neutron diffraction texture measurements.

Degrees conferred

The University of Copenhagen conferred the degree of lic. scient. (Ph.D.) on A. Schrøder Pedersen.

PARTICIPATION IN THE HI-81 EXHIBITION

Risø participated in the Industrial Exhibition which took place in Herning from 8-12 September 1981. The Metallurgy Department contributed posters, slides and working equipment to the stand.

PUBLICATIONS

Incubation Period Models for Determining Friction Stress in Creep - Comment on two Papers by M. McLean.

J.B. Bilde-Sørensen, Scripta Met. 15 (1981) 133-134.

An incubation period model by M. McLean, based on continuous growth of the dislocation network, is criticized for being physically unrealistic. It is shown that a realistic model must be based on the discontinuous growth arising from breakage of attractive junctions in the network, as was done in an incubation period model previously suggested by the present author (Phil. Mag. A 38 (1978) 1-13).

Transmissionselektronmikroskopi af materialer med krystaldefekter. (Transmission Electron Microscopy of Materials with Crystal Defects).

J.B. Bilde-Sørensen, materialnyt, No. 1 (1981) 67-74.

The preparation of various samples for transmission electron microscopy is discussed. Various techniques, including weak-beam microscopy and lattice imaging, are discussed and illustrated with examples on the application of these techniques.

An Experimental Study of the Bauschinger Effect and the Mean Stress in Cu-Al_2O_3 Polycrystals.

P. Brøndsted, In: Deformation of Polycrystals: Mechanisms and Microstructures. Proceedings of the 2nd Risø International Symposium on Metallurgy and Materials Science, Risø, 14-18 September, 1981. Edited by N. Hansen, A. Horsewell, T. Leffers and H. Lilholt (Risø National Laboratory, Roskilde, 1981) 459-466.

Bauschinger experiments over a strain range from 0.5% to 3% have been performed on pure copper and on Cu-Al_2O_3-polycrystals at room temperature. The mean stress in the matrix has been estimated from these measurements. It is shown that the mean stress is independent of forward strain for strains higher than 0.3% at room temperature and it is found that the mean stress is unaffected by grain size in the range from 0.015 mm to 0.050 mm. The mean stress is found to be a linear function of particle volume fraction, and finally it is shown that at room temperature the influence from the mean stress compared with the total work-hardening becomes insignificant at strains higher than 3%.

Radial Concentration and Effect on Temperature of Plutonium formed in UO_2 during Irradiation.

H. Carlsen and D.N. Sah, Nucl. Techn. 55 (1981) 587-593.

The distribution of ^{239}Pu formed in uranium dioxide during irradiation is nonuniform and changes with burnup. This implicates a burnup effect on the fuel temperature distribution.

The total ^{239}Pu concentration during irradiation and its radial distribution at end-of-life has been calculated in low-enriched UO_2 fuel pellets. The processes considered are ^{239}Pu buildup by capture of thermal and resonance neutrons and ^{239}Pu loss by thermal fissions and neutron capture. The calculated total ^{239}Pu content is verified by chemical analysis, and the calculated ^{239}Pu profile by comparison with results from quantitative alpha autoradiography for two fuel specimens.

The effect of a nonuniform radial ^{239}Pu distribution on the fuel temperature profile is evaluated. At a burnup level of 3560 GJ/kg U and a linear heat rating of 50 kW/m, the centerline temperature is calculated to be 245 K lower than that calculated on the assumption that the ^{239}Pu is distributed uniformly.

Diffusion in Stainless Steel Joints brazed with Nickel-based Filler Metals.

J. Christensen and P.D. Nielsen, In: Hart- und Hochtemperaturlöten und Diffusionsschweissen, Proceedings of an International Conference on Brazing, High Temperature Brazing and Diffusion Welding, Essen, 21-22 September, 1981. (Deutscher Verlag für Schweisstechnik, Düsseldorf, 1981) (DVS Berichte, 69) 121-123.

Time-temperature-gap relationship to eradicate the brittle intermetallics formed when brazing stainless steel with two Ni-Cr-B-Si brazing filler metals.

Varmebehandling og konstruktionsståls kærvsejhed. (Heat Treatment and Notch Toughness of Structural Steels).

C.P. Debel, In: Varmebehandling af Stål og andre Metaller (Heat Treatment of Steels and other Metals). Dansk Metallurgisk Selskabs Vintermøde, Scheelsminde, 6-8 January 1981. Edited by E. W. Langer and T.S. Nielsen (Dansk Metallurgisk Selskab, Lyngby, 1981) 129-146.

The fracture toughness of different microalloyed as well as high strength low alloyed steels and weldments are presented and the influence of a post weld heat treatment is demonstrated.

Acoustic Emission from Structural Steels and Weldments.
C.P. Debel, A. Nielsen and W.E. Swindlehurst, Metal Science 15 (1981) 492-504. (Also as Risø-M-2276 (1981) 88 pp.).

The abstract appeared in the previous progress report p. 57.

Atlas (Compact Version) of Defects Revealed by Neutron Radiography on Light Water Reactor Fuel.
J.C. Domanus, In: Neutron Radiography Handbook. Edited by P. von der Hardt and H. Röttger (D. Reidel Publishing Company, Dordrecht, Boston, London, 1981) 118-136. (Also in Risø-M-2320).

From neutron radiographs made routinely at Risø National Laboratory for the quality and performance control of nuclear fuel, radiographs showing typical defects in nuclear fuel were chosen.

The defects were classified according to their location, nature and origin.

A collection of reference neutron radiographs was published as an atlas: "Neutron radiographic findings in light water reactor fuel", in which 36 neutron radiographs are produced on film (in original size) and on paper (twice enlarged).

It is intended to enlarge the collection with further examples of defects occurring in nuclear fuel.

Neutron Radiography at the Risø National Laboratory.
J.C. Domanus, P. Gade-Nielsen, P. Knudsen and J. Olsen, Risø-M-2320 (1981) 70 pp.

In this report six papers are collected which will be presented at the First World Conference on Neutron Radiography in San Diego, U.S.A., 7 - 10 December 1981. They are preceded by a short description of the activities of Risø National Laboratory in the field of post-irradiation examination of nuclear fuel. One of the nondestructive methods used for this examination is neutron radiography. In the six conference papers different aspects of neutron radiography performed at Risø are presented.

NRWG Indicators for Testing of Beam Purity, Sensitivity, and Accuracy of Dimensions of Neutron Radiographs.

J.C. Domanus, In: Neutron Radiography Handbook. Edited by P. von der Hardt and H. Röttger (D. Reidel Publishing Company, Dordrecht, Boston, London, 1981) 108-117.

For the sake of testing the radiographic image quality and accuracy of dimension measurements from neutron radiographs of reactor fuel, the NRWG has decided to produce and test special indicators developed for that purpose.

It was decided to produce the following indicators for neutron radiography of nuclear fuel:

- Beam Purity Indicator - BPI.
- Beam Purity Indicator - Fuel - BPI-F.
- Sensitivity Indicator - SI.
- Calibration Fuel Pin - CPP-El.

Those indicators, fabricated at Risø National Laboratory, were distributed among all NRWG participants and will be tested under a special NRWG Test Program.

The Need for Standardization in the Field of Neutron Radiography.

J.C. Domanus, In: Post-Irradiation Examination. Proceedings of a Conference on Post-Irradiation Examination, Grange-over-Sands, 13-16 May 1980. (British Nuclear Energy Society, London, 1981) 326.

Like in other fields on industrial radiography, in neutron radiography of nuclear fuel, standardisation is necessary to be able to use recognized methods for the control of radiographic image quality as well as procedures which will assure that the prescribed quality can be obtained. Having this in mind standardisation work was initiated within Euratom to cope with the different problems of neutron radiography of nuclear elements. Present status of work in this field is reviewed.

Neutron Radiographic Findings in Light Water Reactor Fuel. J.C. Domanus, In: Proceedings of the 1980 Annual Conference of the Canadian Nuclear Society, Montreal, 18 June 1980. Edited by W. Paskievici (Canadian Nuclear Society Toronto, 1981) 325-329.

The assessment of neutron radiographs of nuclear fuel elements can be much easier, faster and simpler if reference can be made to typical defects, which can be revealed by neutron radiography.

During the assessment of neutron radiographs some typical defects of the fuel were found and it was felt that a classification of such defects will help to speed up the assessment procedure. Therefore an attempt was made to establish such a classification, which is currently used at Risø now. This classification is presented in a collaboration of reference neutron radiographs published as an atlas: "Neutron radiographic findings in light water reactor fuel", in which 36 neutron radiographs are reproduced on film (in original size) and on paper (twice enlarged).

The atlas was published by Risø Laboratory within the framework of standardisation work initiated by Euratom.

ISO Wire IQI's vs. ASTM Penetrameters in Paper Radiography. J.C. Domanus and H.M. El Fouly, In: Proceedings of the 2nd European Conference on Non-Destructive Testing, Vienna, 14-16 September 1981. Österreichische Gesellschaft für Zerstörungsfreie Prüfung, Vienna, 1981) 63-67. (Also in Risø-M-2314).

While comparing different properties of radiographic paper with high speed X-ray film, image quality of Al and Fe welds (10, 20 and 30 mm thick) was controlled by the use of ISO wire image quality indicators and ASTM penetrameters. Radiographic sensitivities reached by both methods were compared.

Radiographic Paper for the Quality Control of Joint Structures. J.C. Domanus and H.M. El Fouly, In: Proceedings of the International Conferences on Joining of Metals, JOM-1, Elsinore, 9-12 September 1981. (Edited by O.A.K. Al-Erhayem (Ingeniørhøjskolen Helsingør Teknikum, Helsingør, 1981) 142-148. (Also in Risø-M-2314).

The possibility of using radiographic paper instead of X-ray film in the radiographic quality control of metal-joined structures are discussed. Advantages of this technique are presented: lower material, equipment, and labour costs, shorter exposure and processing times and easier radiation protection. Results of an investigation of radiographic image quality, performed on different brands of radiographic paper and compared with that of fast X-ray film, are given for inspecting aluminium and steel joints. They verify that radiographic paper provides adequate quality for many applications of radiographic control of metal joint structures. Two examples are given of such applications taken from nuclear technology: nuclear fuel and irradiation cans.

Results from Three Dimensional Sound Field Examinations. H.E. Gundtoft, In: Non Destructive Evaluation in Nuclear Industry. Proceedings of the 4th International Conference on Non-Destructive Evaluation in Nuclear Industry, Lindau, Germany, 25-27 May, 1981. (Deutsche Gesellschaft für Zerstörungsfreie Prüfung, Berlin, 1981) 507-515.

Focused transducers used in automatic tube inspection demands an accurate three dimensional sound field examination system. Our recently developed system fulfills this demand, results from examination of transducers will be presented.

Accurate Three Dimensional Characterization of Ultrasonic Sound Fields (by Computer Controlled Rotational Scanning). H.E. Gundtoft and T. Nielsen, In: Proceedings of the 2nd European Conference on Non-Destructive Testing, Vienna, 14-16 September, 1981. A 12 (Österreichische Gesellschaft für Zerstörungsfreie Prüfung, Vienna, 1981) 46-48. (Also as Risø-M-2296 (1981) 14 pp.).

A rotational scanning system has recently been developed at Risø National Laboratory. It allows sound fields from ultrasonic transducers to be examined in 3 dimensions. Using different calculation and plotting programs, any section in the sound field can be plotted. Results from examination of transducers for automatic inspection are presented.

Deformation of Polycrystals: Mechanisms and Microstructures. N. Hansen, A. Horsewell, T. Leffers and H. Lilholt (editors), Proceedings of the 2nd Risø International Symposium on Metallurgy and Materials Science, Risø, 14-18 September 1981. (Risø National Laboratory, Roskilde, 1980) 490 pp.

This symposium has sought to promote the understanding of microstructural development during the deformation of polycrystalline materials and its relation to their mechanical properties. In doing so the symposium has provided a common focus for areas of metallurgy not normally considered together. The papers presented at the symposium are divided into four topics: deformation at low temperature, deformation at high temperature, cyclic deformation and multiple strengthening. Many of the papers relate descriptions of the properties of engineering materials to the fundamental principles discussed in others. An important objective of the symposium has thus been achieved: the successful combination of the theoretical and the applied aspects of polycrystal deformation.

Microstructures in Cold-Rolled Polycrystalline Aluminium. B. Bay and N. Hansen, In: Deformation of Polycrystals: Mechanisms and Microstructures. Proceedings of the 2nd Risø International Symposium on Metallurgy and Materials Science, Risø, 14-18 September, 1981. Edited by N. Hansen, A. Horsewell, T. Leffers and H. Lilholt (Risø National Laboratory, Roskilde, 1981) 137-144.

Deformation structures in pure aluminium and in aluminium of commercial purity were studied by transmission electron microscopy. The materials were produced in coarse-grained and in fine-grained states and cold-rolled to 15% and 30% deformation. In all specimens the subgrains showed a large variation in mean size from grain to grain. The subgrain structure was rather uniform within individual grains. In the coarse-grained specimens slip bands were observed which often were disturbed in the vicinity of a grain boundary; in a limited number of the grains the grain boundary region exhibited subgrains which were larger or smaller than were found in the grain interior. The deformation structures in pure aluminium and in aluminium of commercial purity were rather similar; however the lattice rotation tended to be larger in the pure aluminium. The microstructure examined are discussed in terms of theories for polycrystalline hardening.

Kolddeformation og rekrystallisation af aluminium af kommerciel renhed. (Cold Rolling and Recrystallization of Aluminium of Commercial Purity).
B. Bay and N. Hansen, In: Varmebehandling af Stål og andre Metaller (Heat Treatment of Steels and other Metals). Dansk Metallurgisk Selskabs Vintermøde, Scheelsminde, 6-8 January 1981. Edited by E.W. Langer and T.S. Nielsen (Dansk Metallurgisk Selskab, Lyngby, 1981) 243-257.

The recrystallization behaviour of aluminium of commercial purity is reviewed with special emphasis on the formation and growth of recrystallization nuclei as studied by transmission electron microscopy and high voltage electron microscopy. Furthermore, the structure after cold working is discussed in relation to structural features, which may act as nucleation sites, e.g. deformation bands, cumulative misorientation at grain boundaries and deformation zones at large intermetallic $FeAl_3$ particles.

Recrystallization Kinetics in Copper Investigated by In Situ Texture Measurements by Neutron Diffraction.
N. Hansen, T. Leffers and J.K. Kjems, Acta Met. 29 (1981) 1523-1533.

The abstract appeared in the previous progress report p. 58.

The Interaction between Particles and Low Angle Boundaries During Recovery of Aluminium-Alumina Alloys.
A.R. Jones and N. Hansen, Acta Met. 29 (1981) 589-599.

Certain quantitative and qualitative aspects both of subgrain growth and of the interaction between particles and low angle grain boundaries during recovery have been investigated in two aluminium alloys containing low volume fractions of small alumina particles. Quantitative data have been obtained which indicate the frequency of interaction between particles and low angle grain boundaries during recovery. This frequency is found to be considerably higher than would be expected on the basis of random interaction between boundaries and particles. Further, experimental evidence is presented which shows that there are a number of different categories of interaction between particles and low angle grain boundaries during recovery. Certain of these types of interaction event have previously been undocumented. Hence, it is shown that the full range of particle interactions with low angle boundaries during recovery involves effects in addition to those of simple Zener pinning of migrating boundaries. For the current alloys it is found that a determination of the limits to normal subgrain growth in terms of a modified Zener analysis produces an underestimate of the true extent of particle pinning. The discrepancies between the experimental and theoretical results can be rationalised in terms of the limited nature of the physical effects modelled in the Zener analysis.

Microstructural Evidence of Additive Strengthening.
B. Ralph and N. Hansen, In: Deformation of Polycrystals: Mechanisms and Microstructures, Proceedings of the 2nd Risø International Symposium on Metallurgy and Materials Science, Risø, 14-18 September, 1981. Edited by N. Hansen, A. Horsewell, T. Leffers and H. Lilholt (Risø National Laboratory, Roskilde, 1981) 473-478.

Observations made by transmission electron microscopy of deformation substructures are presented. Fine-grained pure copper samples and similar samples containing a dispersion of alumina particles have been tensile deformed to strains of 0.05, 0.10 and 0.20 at room temperature. The presence of grain boundaries is seen to have a strengthening effect on the microstructure by virtue of a modification in the deformation cell characteristics. The dispersed alumina has an additive effect which is particularly pronounced when the particles are associated with boundaries.

Initial Stages of Recrystallization in Aluminium Containing both Large and Small Particles.
N. Hansen and B. Bay, Acta Met. 29 (1981) 65-77.

The recrystallization behaviour has been studied in dispersion strengthened aluminium-alumina alloy containing a bimodal distribution of fine alumina particles (<0.1 μm) and coarse $FeAl_3$ particles (0.2-4 μm). The formation and growth of recrystallization nuclei were studied by in situ annealing in a high voltage electron microscope, conventional transmission electron microscopy and light microscopy. The parameters studied were the initial grain size and the degree of deformation (50 and 90% reduction in thickness by cold-rolling). It was found that recrystallization nuclei formed preferentially at the initial grain boundaries and at deformation bands; the effect of such sites was enhanced by $FeAl_3$ particles which, however, in isolation were not strong nucleation sites. The recrystallization kinetics in the aluminium-alumina alloy were retarded or accelerated due to the presence of alumina or $FeAl_3$ particles respectively. However, the $FeAl_3$ particles did not lead to a significant grain refinement; the recrystallized grain size of the aluminium-alumina alloy was large. Finally, the structural and kinetic observations are discussed and related to results from a previous study of the initial stages of recrystallization of aluminium of commercial purity.

On the Possible Role of Stoneley Waves in High Temperature Deformation.

A. Horsewell and A.R. Thölén, In: Deformation of Polycrystals: Mechanisms and Microstructures. Proceedings of the 2nd Risø International Symposium on Metallurgy and Materials Science, Risø, 14-18 September, 1981. Edited by N. Hansen, A. Horsewell, T. Leffers and H. Lilholt (Risø National Laboratory, Roskilde, 1981) 299-304.

The propagation of Stoneley waves along grain boundaries between anisotropic crystals is considered using copper as an example. Conditions for propagation and non-propagation of Stoneley waves have been computed for a number of grain boundary planes and misorientation angles. The results are discussed with reference to creep deformation where the interplay between possible Stoneley waves, grain boundary sliding and creep cavitation is considered.

Microstructure and Deformation of WC/Co Cemented Carbide.

S. Vuorinen and A. Horsewell, In: Proceedings of the 2nd Scandinavian Symposium in Materials Science, Hartola 16-18 June, 1981. (Tampere University, Tampere, 1981) 141-147.

Microstructural observations have been made using transmission electron microscopy of deformed and undeformed WC/Co cemented carbides. Deformation substructures within the component phases are discussed alone and in terms of an overall WC/Co compatible deformation.

Microstructure and Orientation Relationship of the TiC/WC Interface.

S. Vuorinen and A. Horsewell, In: Proceedings of the 2nd Scandinavian Symposium in Materials Science, Hartola, 16-18 June, 1981. (Tampere University, Tampere, 1981) 29-37.

The TiC/WC interface formed by the chemical vapour deposition of TiC onto WC grains in cemented carbides has been investigated by transmission electron microscopy. Coherent layers of TiC grains are found on the dominant {1010} and {0001} surfaces of WC grains. Three different orientation relationships are found on {1010} and one on {0001}. Misfit accommodation is discussed.

Orientation Relationship at the TiC/WC Interface.
S. Vuorinen and A. Horsewell, In: Impact of Crystallography, Proceedings of a Meeting on the Impact of Crystallography on Natural Sciences in the 20th Century, Copenhagen, 18-19 May, 1981. (Danish National Committee of Crystallography, Copenhagen, 1981) 16.

The initial nucleation and growth of TiC on WC crystals is reported to occur coherently on the {1010} and {0001} surfaces of WC. There is a specific orientation relationship in the first layer of deposited TiC crystals of thickness 0.05 μm.

The Formation of Multipoles during the High Temperature Creep of Austenitic Stainless Steels.
P.R. Howell, J.O. Nielsson, A. Horsewell and G. Dunlop, J. Mater. Sci. 16 (1981) 2860-2866.

It is shown that multipole dislocation configurations can arise during power-law creep of certain austenitic stainless steels. These multipoles have been analysed in some detail for two particular steels (Alloy 800 and a modified AISI316L) and it is suggested that they arise either during instantaneous loading or during the primary creep stage. Trace analysis has shown that the multipoles are confined to {111} planes during primary creep but are not necessarily confined to these planes during steady-state creep unless they are pinned by interstitials.

Ny energiform: metaller lagerpiads for brint. (A new Form of Energy: Metals as a Storage Medium for Hydrogen).
J. Kjøller and B. Larsen, Metal No. 9 (1981) 6.

Some general outlines of the research on metal hydrides as energy storage media at Risø.

Risø undersøger om man kan forlænge uranstaves driftstid. (Risø examines the Possibility of prolonging the Life of Uranium Fuel Pins).
P. Knudsen, ingeniøren 7, No. 14 (1981) 4.

An overview is given of the internationally sponsored Risø Fission Gas Project, based on UO_2-Zr fuel pins with peak pellet burnup exceeding 40,000 MWD/tU.

Risø fissionsgas projekt. (Risø Fission Gas Project).
P. Knudsen, Kort Nyt, No. 173 (1981) 4-6.

An overview is given of the Risø internationally sponsored Fission Gas Project. The objective of this project is to provide well-characterized experimental data on fission gas release and other aspects of the high-burnup performance of water reactor fuel. The project utilizes UO_2-Zr fuel pins with peak pellet burnup exceeding 40,000 MWD/tU.

Short Report of the National Programmes Presented at the IAEA IWG-FPT in Vienna 3-5 February 1981.
P. Knudsen, In: Proceedings of the IAEA Specialists' Meeting on High Burnup in Power Reactor Fuel, Mol, Belgium, 24-27 March 1981. (IAEA, Vienna, 1981) 7.

An overview is given of the national programmes presented at the 1981 meeting of IAEA's International Working Group on Water Reactor Fuel Performance and Technology, with emphasis on investigations beyond 30,000 MWD/tU.

Microstructures and Mechanisms of Polycrystal Deformation at Low Temperature.
T. Leffers, In: Deformation of Polycrystals: Mechanisms and Microstructures. Proceedings of the 2nd Risø International Symposium on Metallurgy and Materials Science, Risø, 14-18 September, 1981. Edited by N. Hansen, A. Horsewell, T. Leffers and H. Lilholt (Risø National Laboratory, Roskilde, 1981) 55-71.

There are two fundamentally different groups of models for the plastic deformation of polycrystals: the Taylor-type and the Sachs-type models. The Taylor-type models, based on the assumption that there is (at least locally) a homogeneous pattern of multiple slip, emphasize the continuum aspects. The Sachs-models refer to a situation where primary slip is basically different from secondary slip; in the extreme case of the original Sachs model secondary slip is totally neglected. The two types of models are discussed in terms of the internal stresses and microstructures that they imply. The stress/strain curves and their dependence on grain size and the textures derived from the different models are also described and compared with experimental results. The possibility of combining elements from the two types of models is considered.

Bestrålingseffekter i Metaller. (Irradiation Effects in Metals).

T. Leffers and B.N. Singh, Jernkont. Ann. 165, No. 2 (1981) 58-62.

The basic processes in radiation damage are briefly reviewed in terms of creation and agglomeration of point defects. The effects of point-defect agglomeration on the behaviour of metallic reactor materials are described: irradiation-induced embrittlement, void swelling, irradiation creep, irradiation-induced phase changes.

Recombination Cross Section for Interstitials and Vacancies as a Function of Vacancy Concentration.

T. Leffers and B.N. Singh, Radiation Effects 59 (1981) 83-89.

In a previous work it was shown by computer simulation of point-defect migration that the recombination cross section z_{iv} is substantially smaller than normally quoted in literature. In the present work we use a different type of computer program that, unlike the former program, includes the actual recombination event. This makes it possible to cover the range of vacancy concentrations from very high values down to 10^{-5} and to include the case where interstitials and vacancies are equally mobile. We are therefore in a position to establish the dependence of z_{iv} on the various relevant parameters. The relation between the present atomistic approach and the alternative continuum approach is discussed.

Tilsætningsmaterialers betydning for kompositegenskaber: fiberformede tilsætningsmaterialer. (The Effect of Fillers on Composite Properties: Fibrous Fillers).

H. Lilholt, In: Plastbaserede Kompositmaterialer (Polymer-based Composite Materials). Edited by J. Moustgaard (Teknologisk Institut, Tåstrup, 1981) 43-67.

A brief survey of the mechanical behaviour of fibre-reinforced composite materials is given.

Fremstilling af fiberforstærkede vindmøllevinger prioriteres nu højt. (Production of Fibre-Reinforced Rotor Blades for Wind Turbines has a High Priority).

Aa. Lystrup, Dansk Tekn. Tidsskr. 105, No. 3 (1981) 7-10.

Wingblades for a 630 kW windturbine are described. The conceptual design of the 20 m long wingblades comprises a load-bearing spar with aerodynamically shaped shells. The 12 m outer spar is made of highly directional glass fibres in a polyester matrix. The spar is fabricated by a special tape winding technique, which gives a high volume fraction of glass fibres oriented nearly parallel to the spar axis.

Undersøgelser af reaktionen mellem hydrogen og jern-titan. (Studies of Hydrogenation Properties of the Intermetallic Compound FeTi).

A. Schrøder Pedersen, Risø-M-2288 (1981) 103 pp.

The literature on hydrogen uptake in FeTi has been briefly reviewed, and the most important uptake data are given.

Samples of FeTi have been activated, and the specific surface areas determined using the BET model. Activation seems to imply a specific surface area of about 0.5 m^2/g independent of the initial mean particle size.

The hydrogen uptake in FeTi at low pressures (0-1000 torr) has been studied at low temperatures (80-90 K) and in the 300-500 K range. At low temperatures a dissociative, nonactivated Temkin adsorption process is found. In the high temperature range a dissolution is dominating, and diffusion seems to be the rate limiting step. A measured value of the activation energy for diffusion is given.

Data on the hydrogen adsorption in the α-β equilibrium range are given. The data suggest that one well defined process determines the rate of absorption. The uptake isotherm deviates somewhat from what has been reported earlier.

Persistent Slip in Copper Polycrystals.

O.B. Pedersen, In: Deformation of Polycrystals: Mechanisms and Microstructures. Proceedings of the 2nd Risø International Symposium on Metallurgy and Materials Science, Risø, 14-18 September, 1981. Edited by N. Hansen, A. Horsewell, T. Leffers and H. Lilholt (Risø National Laboratory, Roskilde, 1981) 451-457.

Recent work implies that a bulk dispersion of persistent slip bands controls the fatigue deformation of sufficiently coarse-grained polycrystals, exactly as in single crystals. This model is expected to break down if the grains become sufficiently small or if the strain amplitude becomes sufficiently high. Experiments made to examine these limitations are described.

The Bauschinger Effect in Copper.

O.B. Pedersen, L.M. Brown and W.M. Stobbs, Acta Met. 29 (1981) 1843-1850.

A study of the Bauschinger effect in pure copper shows that by comparison with dispersion hardened copper the effect is very small and independent of temperature. This suggests that the obstacles to flow are deformable. A simple composite model based on this principle accounts for the data semi-quantitatively and also accounts for the stored energy of cold-work. An interesting feature of the model is that it shows very clearly that, although dislocation pile-ups may exist, the flow stress of the composite is entirely due to the resistance to dislocation motion in the tangles of forest dislocations.

Dislocation Microstructures in Fatigued Copper Polycrystals.

A.T. Winter, O.B. Pedersen and K.V. Rasmussen, Acta Met. 29 (1981) 735-748.

Dislocation structures characteristic of persistent slip bands were observed in the interior of polycrystalline copper after fatigue. At low strain amplitudes, within the plateau on the cyclic stress-strain curve, only structures identical to those seen in single crystals were observed. This allows the stress amplitude of the plateau to be calculated. At higher strain amplitudes, above the plateau, more complex structures were found. Further work will be needed to establish the nature of these new structures, but it seems clear that the increase in stress amplitude is connected with their appearance.

Ionic Conductivity of Solid Lithium Iodide and its Monohydrate.
F.W. Poulsen, Solid State Ionics 2 (1981) 53-57.

The solid electrolytes LiI, LiI,H_2O and LiI,D_2O have been characterized by ac- and dc-conductivity measurements. LiI exhibits two conductivity regions: an extrinsic below ~ 180°C and an intrinsic above, with activation energies of 0.43 ± 0.04 eV and 0.81 ± 0.05 eV respectively. The room temperature conductivities of the hydrates LiI,H_2O and LiI,D_2O are 6.6×10^{-6} and 6.1×10^{-6} $(\Omega\ cm)^{-1}$ respectively. The activation energy for Li-ion motion in LiI,D_2O is 0.66 ± 0.05 eV.

Configurational Model for Conductivity of Stabilized Fluorite Structure Oxides.
F.W. Poulsen, Solid State Ionics 5 (1981) 535-538.

A model for oxide ion conducting solids is set forward. Ionic configurations, solid solution limits, and conductivity mechanisms in doped fluorite structure oxides are described in the model.

Forskning i energilagre. (Research into Energy Storage).
F.W. Poulsen, Dansk Tekn. Tidsskr. 105, No. 2, (1981) 4-8.

The materials research programme carried out at the Metallurgy Department on solid electrolytes for future use in advanced traction batteries is outlined. Demands to materials properties and the research strategy is discussed.

Raman Spectroscopic Study of PCl_5-$AlCl_3$ Melts.
F.W. Poulsen, J. Raman Spectroscopy 11 (1981) 302-305.

Raman spectra of the superacidic melt system PCl_5-$AlCl_3$ are reported. The melt species have been identified. Relative molar scattering intensities of the six melt species are given.

Some Observations on Nucleation and Growth of Voids and Dislocation Loops in Low Dose Neutron Irradiated Copper.

B.N. Singh and T. Leffers, Vaprosy Atomnoi Nauki i Tekhniki, series Fizika Radiatsionnykh Povrezhdenii i Radiatsionnoye Materialovedenie, 15 (1981) 3-8.

High purity copper specimens were irradiated in the DR-3 reactor at Risø to doses of $1 \cdot 10^{22}$ and $5 \cdot 10^{22}$ neutrons(fast)/m^2; the irradiation experiments were carried out at 250°C. The irradiated specimens were examined by transmission electron microscopy. At both doses, the irradiation induced structure was found to be highly segregated: the dislocation loops and segments were present in the form of irregular walls and the voids were found to be distributed between these walls. The dislocation walls were found to be free of voids whereas the dislocations were almost entirely absent in the region containing voids. The implications of this kind of segregated distribution on void formation and growth are briefly discussed.

The Effect of High Rate of Gas Generation on the Formation and Spatial Distribution of Cavities in Aluminium Irradiated with 600 MeV Protons.

B.N. Singh, T. Leffers, W.V. Green and S.L. Green, Scripta Met. 15 (1981) 1355-1358.

In the first wall of a fusion reactor the high-energy (14 MeV) neutrons will produce a type of radiation damage different from that experienced by the canning materials in fission reactors: in addition to displacement damage there will be a high rate of helium and hydrogen generation by mutational reactions. In the present work these conditions are simulated by 600 MeV proton irradiation of aluminium up to a dose of 2 dpa. The great majority of the visible cavities produced during irradiation are situated near the grain boundaries. One population of very small cavities in the immediate vicinity of the boundaries becomes visible at a dose of about 2 dpa. Another, dual-size, population of bigger cavities at some distance from the boundaries is visible from an earlier stage of irradiation. These observations are discussed in terms of helium diffusion (by a vacancy mechanism).

A Positron Annihilation Investigation of Defects in Neutron Irradiated Copper.

M. Eldrup, J.H. Evans, O.E. Mogensen and B.N. Singh, Radiat. Eff. 54 (1981) 65-80.

The response of positron annihilation parameters to the defect structures produced by neutron irradiation in copper, and their annealing behaviour, have been studied on specimens irradiated at two different temperatures, 50°C and 250°C. Both lifetime and angular correlation measurements were made while some aspects of the irradiation damage substructure were also covered by transmission electron microscopy. Marked changes in the positron parameters were found after the two irradiations. After the 50°C irradiation the dominant TEM defect was a high concentration of small loops, after the 250°C irradiation it was a population of voids. The voids gave rise to a long-lived component (420 ± 75 psec) that disappeared during isochronal annealing to between 450°C and 550°C in agreement with TEM observations. Another trapped positron component (180 ± 7 psec) appearing after both irradiations annealed out between 275 ± 25°C and 475 ± 25°C. Although we could not entirely exclude that the defects giving rise to this trapping were the dislocation loops, the results suggested that the traps were a population of small submicroscopic vacancy clusters (microvoids), probably gas stabilised. This appears to be important since such clusters are usually not considered, although there are good physical arguments to support their existence. The question of positron trapping at dislocations and loops still appears to be an open one.

Estimation of Weibull Parameters for Composite Materials Strength and Fatigue Life Data.

R. Talreja, In: Fatigue of Fibrous Composite Materials, ASTM STP 723. Edited by K. Lauraitis (American Society for Testing and Materials, Philadelphia, 1981) 291-311.

A method for estimating Weibull distribution parameters is proposed. This method provides estimates for all three parameters when the shape parameter is close to one, and estimates the scale and shape parameters more accurately than the classical methods (Moment estimation and maximum likelihood estimation) for higher values of the shape parameter. Furthermore, unlike the other methods, this method is capable of separating the constituent components in a multi-component sample and of estimating the parameters of each component. This property makes the method suitable for statistical analysis of composite material strength and fatigue life data.

Fatigue of Composite Materials: Damage Mechanisms and Fatigue Life Diagrams.

R. Talreja, Proc. Roy. Soc. A378 (1981) 461-475.

The basic fatigue damage mechanisms in composite laminates are reviewed. Based on these mechanisms a pattern in the fatigue-life diagrams is proposed. Several experimental data are shown to agree with this basic pattern. Fatigue ratio is defined in terms of strains, and fatigue limit is shown to exist for unidirectional, cross-plied and angle-plied laminates.

The limitations to the fatigue performance of composite laminates are pointed out and suggestions for improving the fatigue resistance are made.

Udmattelsespåvirkede konstruktioner: dimensionering baseret på brudmekanik. (Fatigue Loaded Structures: Dimensioning based on Fracture Mechanics).

R. Talreja, Project 1, No. 2, (1981) 25-31.

We describe the fracture mechanics approach to dimensioning of structures subjected to fatigue. We then discuss the relation between the threshold value for crack growth and the conventional fatigue limit (given by the Wöhler diagram). Finally, the use of this design method is illustrated by considering welded structures subjected to fatigue.

Quasi-Isothermal Methods in Thermal Analysis.

O. Toft Sørensen, Thermochimica Acta 50 (1981) 163-175.

Compared with conventional non-isothermal analysis, quasi-isothermal methods have the advantages that (1) reaction temperatures can be determined accurately, (2) close-lying reactions can easily be separated, and (3) accurate kinetic data can be determined for each intermediate reaction in a single run. After a short description of the experimental technique, examples of the resolution obtained in quasi-isothermal thermogravimetric studies of thermal decompositions are discussed as well as the advantages obtained in quasi-isothermal dilatometric sintering studies of oxide compacts. Finally, it is demonstrated how kinetic data can be determined from the temperature and weight/length curves recorded in quasi-isothermal thermogravimetric and dilatometric studies.

Thermodynamics and Defect Structure of Nonstoichiometric Oxides.

O. Toft Sørensen, In: Nonstoichiometric Oxides. Edited by O. Toft Sørensen (Academic Press, New York, 1981) 1-59.

A general introduction to nonstoichiometric oxides is given. The following topics are treated:

a. General Thermodynamic Considerations of the Phase Relationships in Nonstoichiometric Oxides
b. Classification of Nonstoichiometric Oxides
c. Thermodynamics and Defect Structure of Oxygen-Deficient Oxides
d. Thermodynamics and Defect Structure of Metal-Deficient Oxides
e. Thermodynamics and Defect Structure of Metallic Transition Metal Oxides
f. Thermodynamics and Defect Structure of Excess-Oxygen Oxides
g. Thermodynamics and Defect Structure of Oxides Existing as both Oxygen-Excess and Oxygen-Deficient Compounds.

Nonstoichiometric Oxides.

O. Toft Sørensen (editor)(Academic Press, New York, 1981) 441 pp.

In the early seventies nonstoichiometric oxides were discussed in several excellent books, but since then many important contributions have improved our understanding of these systems considerably. The aim of this book therefore is to present a detailed and up-to-date account of the present state of the art within this field.

In the first part, the thermodynamic properties of nonstoichiometric oxides are discussed by contributors in terms of defect complexes, first in a very general way using the principles of classical thermodynamics and then from a statistical thermodynamics point of view. The statistical thermodynamic models and the simple treatment clearly indicate that the nonstoichiometric phase range is much more ordered than was previously believed.

In the second part, transport properties, i.e. diffusion and electrical conductivity, are reviewed. First the diffusion theories and experimental diffusion coefficients are discussed for several systems and then the electrical properties are discussed for the highly defective ionic and mixed oxide conductors (fast ionic conductors).

Finally an account is given of the very important results obtained in structural studies using high resolution electron microscopy and X-ray and neutron diffraction. These studies, which supplement each other in an excellent manner, have very convincingly confirmed the fact that defect complexes and ordered structures are really formed in nonstoichiometric oxides.

Quasi-Isothermal Dilatometric Sintering Studies on UO_2 Powder Compacts: Influence of Experimental Parameters.

L. Hälldahl and O. Toft Sørensen, In: Proceedings of the 2nd European Symposium on Thermal Analysis, Aberdeen, 1-4 September 1981. Edited by D. Dollimore (Heyden, London, 1981) 186-190.

The influence of the experimental parameters in quasi-isothermal dilatometry were analyzed and the optimal conditions giving a good sensitivity were selected. Using these conditions the kinetics of densification of UO_2 powder compacts were determined. For the first stage, the activation energies obtained indicate that oxygen diffusion is the controlling mechanism.

Thermogravimetric Studies of Thermodynamic Properties and Defect Structure of Wüstite ($Fe_{1-y}O$) and Cobaltowüstite $[(Co,Fe)_{1-y}O]$.

J. Hinder, J.L. Holm and O. Toft Sørensen, In: Proceedings of the 2nd European Symposium on Thermal Analysis, Aberdeen, 1-4 September 1981. Edited by D. Dollimore (Heyden, London, 1981) 159-164.

Thermodynamic properties of wüstite ($Fe_{1-y}O$) and cobaltowüstite $[(Co,Fe)_{1-y}O]$ were determined as a function of composition by thermogravimetric measurements in atmospheres of controlled pO_2. For low defect concentrations the same type of defect apparently is formed in both systems (16 V_{Fe}'' • 5 $Fe_i^{\cdot\cdot}$-complex, can be considered to be an element of the inverse spinel structure of Fe_3O_4) but at higher defect concentrations a substantial ordering apparently only takes place in the $(Co,Fe)_{1-y}O$-system.

Magnesium for Energy Storage.

B. Vigeholm, Light Metal Age 39, No. 5/6 (1981) 8-22.

Storing hydrogen is an interesting new application of magnesium which may have an impact on our energy situation in a not too far future.

Magnesium reacts readily with hydrogen to form magnesium dihydride at temperatures above 230°C under moderate pressure. The hydrogen is efficiently released at low pressure at slightly higher temperature. Many applications of the magnesium-magnesium hydride system related to energy storage are under development with a few nearly operative.

A brief rewiev of the new technology is given and some specific applications described.

Energi kan lagres som brint i metal. (Energy can be stored in the Form of Hydrogen in Metal).

B. Vigeholm, Dansk Tekn. Tidsskr. 105, No. 5 (1981) 8-11.

Metal hydrides - a chemical compound of metal and hydrogen - have for the last decade been in focus as energy storages. The interest is related to the facts that the metal hydrides have a high energy concentration compared with most other storages and that the stored energy hydrogen contrary to all other fuels is pollution free - as water vapour is the only combustion product.

LECTURES

Non-Destructive Assessment of Fission Gases Released in Water Reactor Fuel Rods.

C. Bagger, presented at the IAEA Specialists' Meeting on Examination of Fuel Assembly for Water Cooled Power Reactors, Tokyo, 9-13 November 1981 (Not available).

The relative fission gas concentration in a number of water reactor fuel rods of similar design and base-irradiation history was measured by gamma spectrometry of ^{85}Kr in the plenum area. Analysis of the plenum gas from a single rod after puncturing was used to convert the ^{85}Kr activity to absolute fission gas concentration. Subsequent puncturing results showed with a single exception the accuracy of the non-destructive assessment to be comparable to the accuracy of puncturing. Presence in the collimating line of major amounts of ^{58}Co from fast neutron reaction with Ni obstructs the measurement of ^{85}Kr.

Transmissionselektronmikroskopi af materialer med krystaldefekter. (Transmission Electron Microscopy of Materials with Crystal Defects).

J.B. Bilde-Sørensen, presented at Dansk Selskab for Materialprøvning og - forskning's Meeting on the Applications of Electron Microscopy, Lyngby, 22 April 1981. (Manuscript published in materialnyt No. 1 (1981) 67-74).

Chassiser fremstillet ved dyppelodning. (Assembling Chassis by Dipbrazing).

J. Christensen, presented to Dansk Forening for Apparatteknik, Lyngby, 20 May 1981. (Not available).

As the dip-brazing process is practically unknown to the Danish designers for assembling aluminium parts e.g. chassis for minor apparatus, this process was shortly presented by a discussion of the detailed procedures. It was emphasized that this process is very well fit for unskilled but careful workers to reproducibly produce components to very narrow tolerances and with great confidence to the brazed joints. This process is also very well fit for mechanizing and is easily controlled by quality assurance. It was also emphasized that the precipitation hardening alloys are specially suitable for the dip-brazing process, as the solution heat treatment can be a part of the brazing process, whereas the work hardening aluminium alloys are less suitable, as they will loose their properties obtained by cold working.

Finally the use of the dip-brazing process was demonstrated by a presentation of a series of dip-brazed and very complicated chassis for use in electronic apparatus with very high demands to tolerances and quality of the brazed joints.

Wettability and Bending Strength of 11 Cadmium-Free Silver Brazing Filler Metals.

J. Christensen, presented at a conference on Joining of Metals - Practice and Performance, Warwick, 10-12 April 1981. (Proceedings to be published).

Due to recent Danish legislation restricting the use of cadmium bearing brazing filler metals, 11 commercially available cadmium-free silver bearing brazing filler metals have been investigated to compare the wettability and bending strengths of joints in steel and copper, made using Ag-Cu-Zn-Sn filler, and in stainless steel, made using Ag-Cu-In-Ni filler. The wettability, investigated using the sessile drop test, was considered in terms of the brazing temperature and the filler/flux combination. The bending strength was determined using the recommended combination of filler metal and flux and a brazing cycle in accordance with DIN 8525 (P2). The investigations have shown that acceptable results have been obtained using most of the filler metal/flux combinations, although brazing temperature higher than those recommended were needed in some cases. Brazing filler metal/flux combinations delivered from the same supplier did not always give optimum wettability. Some of the cadmium-free silver brazing filler metals showed liquation using the heating cycle corresponding to DIN 8525 (P2). Likewise, there was some indications that a high tin content (5%) may cause brittle joints.

Characteristics of Brazed Joints in High Temperature Materials. J. Christensen, and G.E. Sheward, presented at the European Symposium on the Behaviour of Joints in High-Temperature Materials, Petten, 14-15 May 1981. (Proceedings to be published).

Brazed joints are being increasingly used to manufacture assemblies for high temperature applications - in many cases for use in critical situations in which the penalty of failure is high. Although much information has been published on the properties of brazed joints, the data is frequently related to a specific application, and so there is a shortage of general information on the basic properties of brazed joints made in high temperature materials. This paper will therefore review their characteristics, discussing the effects of the brazing cycle, the parent metal/filler metal reactions, component and joint design and heat treatment on the properties of the brazed component. The application of quality control procedures can be applied with confidence and make the high temperature brazing process one of the most reproducible of all the joining processes. Finally, recommendations are made about further research and development to obtain a better knowledge of the basic nature of brazed joints and the brazing process, so that it can be more widely applied with greater confidence.

How good is Nitrocellulose Film for Neutron Radiography? J.C. Domanus, presented at the First World Conference on Neutron Radiography, San Diego, 7-10 December 1981 (Published in Risø-M-2320 (1981). Proceedings to be published).

A comparison was made of radiographic quality and sensitivity of neutron radiographs taken on silver halide and nitrocellulose film. For the quality comparison a special calibration fuel pin was used, containing calibrated fuel-to-clad gaps between the UO_2 pellets and zircaloy cladding tube. The neutron radiographs of this pin were assessed by three observers for radiographic image quality referred to X-ray radiographs of the pin.

The radiographic sensitivity was investigated with ASTM E 545 sensitivity indicators and assessed in the same way as the calibration fuel pin.

As the neutron radiographs taken on nitrocellulose film are usually not directly assessed from the original nitrocellulose film but from their copies during the investigation the nitrocellulose films were copied on high contrast graphic film (Kodalith), direct reversal film (Kodatone), and enlarging paper (Kodabrom). They were also viewed through polarising filters.

Results of the quality and sensitivity assessment done for the nitrocellulose film by the methods described above were compared with those for the silver halide film used in the direct and transfer neutron radiography of the same objects.

Defects Revealed by Neutron Radiography.

J.C. Domanus, poster presented at the First World Conference on Neutron Radiography, San Diego, 7-10 December 1981. (Not available).

Atlas "Neutron radiographic findings in light water reactor fuel", published in 1979 by the Risø National Laboratory Metallurgy Department is shown as an illuminated table together with sound slides on a projector.

Euratom Test Program for Image Quality and Accuracy of Dimensions.

J.C. Domanus, presented at the First World Conference on Neutron Radiography, San Diego, 7-10 December 1981. (Published in Risø-M-2320 (1981). Proceedings to be published).

The Neutron Radiography Working Group constituted within Euratom in 1979 has developed a test program for checking the image quality and accuracy of dimensions measured from neutron radiographs of nuclear fuel pins. For that program specially designed and produced at Risø: calibration fuel pin beam purity indicators and sensitivity indicator will be used. They will be neutron radiographed together at each of the neutron radiography centers, participating in the NRWG. Silver halide X-ray films will be exposed with Gd and Dy converters by the direct and transfer method. Nitrocellulose film coated on both sides with a converter and without coating, but between two converter screens, will also be used. The radiographs will thereafter be processed at the centers themselves as well as at Risø. The results will be compared and conclusions drawn about the suitability of the test items for the purpose of assessing the neutron beam constituents, the image quality and the accuracy of dimension measurements.

Nuclear Industry Application of Neutron Radiography in Europe.

J.C. Domanus and P. von der Hardt, presented at the First World Conference on Neutron Radiography, San Diego, 7-10 December 1981. (Proceedings to be published).

A review is given of neutron-radiography facilities in countries within the Commision of the European Communities. Those facilities are mainly used for nuclear applications.

Search for Adequate Quality Standards for Neutron Radiography of Nuclear Fuel.

J.C. Domanus, presented at the First World Conference on Neutron Radiography, San Diego, 7-10 December 1981. (Published in Risø-M-2320 (1981). Proceedings to be published).

Unlike in other fields of industrial radiography, where standard methods and procedures are used to control the quality of the radiographic image, no such standard exist for neutron radiography of nuclear fuel. To fill that gap it was felt that standardization work ought to be started in that field, too.

Therefore different design of beam purity and sensitivity indicators were envisaged, discussed and analysed by the NRAG and finally produced, to be tested under a special test program. The separate problem of testing the accuracy of measurement of different dimensions of nuclear fuel pins from neutron radiographs is under consideration by the NRGW. This problem can be solved by the use of calibration fuel pins, simulating the true nuclear fuel pins and containing such calibrated items as fuel-to-clad gaps, pellet-to-pellet gaps, central voids, dishings. By the use of such calibration fuel pins accuracy of dimension measurements will be tested under the same test program as mentioned above. Neutron radiographs of the calibration fuel pins will be also used to assess adequacy of use of various measuring instruments and methods.

Evaluation of a Minicomputer Controlled Scanning System for Nondestructive Examination.

H.E. Gundtoft, presented at a meeting in the Danish Physical Society on Mini- and Microcomputers in Experimental Physics, Lyngby, 26 March 1981. (Not available).

A general discription at how we use minicomputers in our non-destructive examination. As an example a more detailed explanation of the use of a PDP11 computer in our scanning system for examination of ultrasonic sound fields in water.

Research at Risø National Laboratory (with Emphasis on Materials Research).

N. Hansen, presented at Noranda Research Laboratory, Montreal, Canada, 23 March 1981. (Transcript available).

The research activities at Risø National Laboratory is reviewed with special emphasis on the materials research programme in the nuclear area and in the non-nuclear energy field. Among the nuclear subjects were: extraction of uranium from Kvanefjeld ore in Greenland, development of fuel elements for water cooled reactors and storage of radioative waste. Other subjects were: neutron radiography, neutron diffraction research, fiber composites, propellers for windmills and materials for chemical and electrochemical energy storage.

Recovery and Recrystallization of Particle Containing Materials.
N. Hansen and A.R. Jones, presented at the 24'eme Colloque de Metallurgie: Les Traitements Thermomécaniques: Aspects Théoriques et Applications, Saclay 16-18 June 1981. (Proceedings to be published).

The recovery and recrystallization of metals containing a dispersion of small particles (diameter < 0.1 μm) is reviewed with special emphasis on the behaviour of aluminium-aluminium oxide alloys. It is shown that the retardation of recovery and recrystallization caused by the presence of small particles involves pinning of both low and high angle boundaries, which effects subgrain growth, growth of recrystallizing grains and grain growth subsequent to recrystallization. It is finally demonstrated that the shape, the size and the size distribution of grains in the recrystallized state and after grain growth is a function of size, distribution and volume fraction of the dispersed particles.

Neutron Scattering Studies of the Ionic Conductor $LiI \cdot H_2O$.
N. Hessel Andersen, J. K. Kjems and F.W. Poulsen, presented at the Nordic Solid State Physics Conference, Copenhagen, 10-12 August 1981. (To be published in Physica Scripta).

The structural properties of the ionic conductor $LiI \cdot D_2O$ have been studied by neutron scattering. The cubic room temperature α-phase, Pm3m, is disordered both wiht respect to the occupation of the Li^+-positions and to the orientations of the water molecules. A first order phase transition from the the α-phase to a new orthorhombic β-phase, $P2_1am$ or Pmam, has been found at -54°C. The structural parameters of the β-phase have been determined by the Rietveld method based on powder diffraction data. The β-phase is found to have an antiferroelectric ordering of the water molecules and a spatial ordering of the Li^+-sites. Evidence for short range order is found in the diffuse elastic scattering in the α-phase and the implications for the ionic conductivity are discussed.

The Study of Microstructure and Crystallography at the TiC/Cemented Carbide Interface.
S. Vuorinen and A. Horsewell, presented at the International Conference on the Science of Hard Materials, Jackson Lake, Wyoming, 23-28 August 1981. (Proceedings to be published).

Chemical vapour deposition of TiC onto WC/Co cemented carbide substrates is shown to be determined largely by the chemical and crystallographic nature of the substrate. Morphology and grain size changes in the TiC layer occur parallel to the interface and vary with substrate composition. Specific orientation relationships between TiC and WC are reported.

Neutron Diffraction Texture Measurements as a Tool for the Investigation of Recrystallization Kinetics.

D. Juul Jensen, N. Hansen, J.K. Kjems and T. Leffers, presented at the 6th International Conference on Textures of Materials, Tokyo, 28 September - 3 October 1981. (Proceedings to be published).

A novel experimental set-up for on-line recording of pole figures by neutron diffraction during recrystallization is described. The application is demonstrated in a kinetic investigation of the recrystallization of fine-grained and coarse-grained copper.

Six Years Experience with the Double Beam Neutron Radiography Facility at the Risø National Laboratory.

P. Knudsen and J. Olsen, presented at the First World Conference on Neutron Radiography, San Diego, 7-10 September 1981. (Published in Risø-M-2320 (1981). Proceedings to be published).

The Risø neutron radiography (NR) facility utilizes a homogeneous solution-type reactor (L-55, Atomics International) as the neutron source. Two horizontal, parallel neutron beams, each having a cross section of 10 x 10 cm and a thermal neutron flux of 10^6 n/cm^2·s are available. The collimators are so arranged that the L/D-ratio vertically and horizontally is 110 and 30, respectively.

The principal application of the Risø facility is the nondestructive examination of water reactor fuel, i.e. Zircaloy clad uranium dioxide. This has included 3 m long power reactor fuel rods and 15-200 cm fuel rods from test reactor irradiations. Pin lengths up to 4 1/2 m can be examined. The burnup of some of this fuel exceeds 50,000 MWD/tU.

The NR technique is useful for the characterisation of features which would otherwise normally require destructive examination. Examples are: pellet cracks and center voids, local hydriding of the cladding, and presence of water in defect fuel rods. The usefulness of the technique is very much increased by detailed correlation with other methods such as visual inspection, eddy-current testing, axial gamma scanning, and profilometry. Consequently, it is possible to limit the costly destructive examinations, such as metallography, to sample locations of real importance.

The paper presents typical and illustrative examples from the six years of NR experience at Risø.

The {111} Rolling Texture Component in Brass and its Relation to the Formation of the Brass-Type Texture.

T. Leffers, presented at the 6th International Conference on Textures of Materials, Tokyo, 28 September - 3 October 1981. (Proceedings to be published).

In the fully developed brass-type texture there is a weak texture component with {111} parallel to the rolling plane which has gone through a maximum at about 85% reduction. It has been suggested that the formation of this texture component, by overshooting resulting from the presence of mechanical twins, is a necessary intermediate stage in the development of the brass-type texture. In the present work it is argued, on the basis of available experimental evidence, that the {111} component is merely a deviation in - and not the reason for - the formation of the brass-type texture.

Additive Strengthening.

H. Lilholt, presented to the 2nd Risø International Symposium on Metallurgy and Materials Science, Risø, 14-18 September 1981. (Transcript available).

A review is presented on the addition of strengthening contributions, with emphasis on polycrystalline materials and dispersion hardened materials. A systematic conversion between shear and tensile stress-strain curves is proposed with reference to the hardening rates. Rules of addition are established for obstacles of intermixed distributions and for obstacles of regional distributions. The strength contributions are discussed: the mean stress, the "source-shortening" stress and the forest stress. Materials of non-homogeneous microstructure can behave in two different ways: unrelaxed behaviour and relaxed behaviour. The reasonably well understood microstructure and internal stresses of dispersion hardened materials are used in an attempt to describe the behaviour of polycrystalline materials. The differences between the stress values from an averaged dislocation arrangement and a localized arrangement are discussed.

Windturbines and Fibre Composites.

H. Lilholt, presented to the Engineering Department, Cambridge University, 4 December 1981; The Materials Development Division, Harwell, 7 December 1981; BP Research Centre, Sunbury-on-Thames, 10 December 1981; School of Engineering, University of Bath, 11 December 1981. (Not available).

The use of fibre composite materials for the wingblades of large windturbines was presented. The materials selection, fabrication and materials testing of glass/polyester for the load-bearing components was presented.

Armeret plast. (Reinforced Plastics).

H. Lilholt, present to Kemiingeniørgruppen, Dansk Ingeniør Forening, Copenhagen, 18 November 1981. (Not available).

A survey of fibres and their composite materials was given, with reference to their chemical properties and practical application in the chemical industry.

Nye konstruktionsmaterialer i industrien. (New Structural Materials in the Industry).

H. Lilholt and R. Talreja, presented to Dansk Ingeniør Forening, Copenhagen, 1 Oktober 1981. (Not available).

A survey of fibres and composite materials was given, with several examples from actual applications of composite materials.

Kompositmaterialer. (Composite Materials).

H. Lilholt, presented to Plastsammenslutningen, Vejle, 30 April 1981. (Not available).

A survey of fibres and their composite materials was presented.

Fremstilling af fiberforstærkede vindmøllevinger. (Production af Fibre-Reinforced Wingblades).

Aa. Lystrup, presented at Herning-Messen, 9 September 1981. (Published in Dansk Tekn. Tidsskr. 105, No. 3 (1981) 7-10).

Wingblades for a 630 kW windturbine are described. The conceptual design of the 20 m long wingblades comprises a load bearing spar with aerodynamically shaped shells. The 12 m outer spar is made of highly directional glass fibres in a polyester matrix. The spar is fabricated by a special tape winding technique, which gives a high volume fraction of glass fibres oriented nearly parallel to the spar axis.

Metallografi og levetidsvurdering af reformerrør. (Metallography and Estimation of Residual Life of Reformer Tubes).

T.S. Nielsen, presented to Dansk Forening for Materialografi's Novemberseminar, Kolding, 26-27 November 1981. (Not available).

For many years, centrifugally cast HK40 has been the standard material for reformer tubes. Like many other high temperature alloys, HK40 is not structurally stable. The as-cast structure is eutectic carbides in austenite. During service at high temperature, these carbides grow ever coarser. Along with this coarsening, secondary carbides precipitate in the austenitic matrix, coarsen and finally redissolve. Having reached this state, the useful life of the tube is practically spent.

Along with this structural development, creep holes form in connection with the primary, eutectic carbide. The number, degree of coalescence and distribution of creep holes, plus the stage reached in the structural development, make an estimation of residual life possible.

Several different etching procedures are used to reveal the structure elements, and Nomarski Interference Contrast to distinguish creep holes from dark inclusions.

Dislocations and the Theory of Composites.

O.B. Pedersen, presented to the Metal Physics Group, Cavendish Laboratory, Cambridge, 29 October 1980. (Not available).

Recent work shows that a simple mean field model delivers rigorous bounds for the overall behaviour of composite materials and their internal fields. The model offers a clear physical picture of the internal stresses set up by small or large volume fractions of hard ellipsoidal inclusions in a softer matrix. This picture is easily combined with dislocation theories and experimental observations of stress relaxation and obstacle controlled flow. Contributions of the model to an understanding of the Bauschinger effect, fatigue hardening and PSB nucleation in pure metals were presented and discussed.

Electrochemistry of Solids.

P.W. Poulsen, presented to Dansk Elektrokemisk Forening, Lyngby, 23 April 1981. (Not available).

DC, AC and pulse techniques used to characterize bulk and interfacial properties of solid electrolytes are reviewed. The talk presents data from the solid state ion conductor project at Risø.

Electrochemical and Spectroscopical Characterization of Chloride Melts.

F.W. Poulsen, presented at Anorganisch-Chemisches Institut der Technischen Universität München, 9 Januar 1981. (Not available).

General characteristics of molten salts and their industrial applications are discussed. The very complicated chemistry of chloroaluminate melts are treated in depth, in particular the redox chemistry of S, Se, and Te are covered. Application of chloroaluminate melts in high temperature advanced batteries is discussed.

Study of Lithium Halide Hydrates.

F.W. Poulsen, presented at the 4th EUCHEM Conference on Electrochemical Energy Storage, Solid Materials for Advanced Batteries, Gradignan, 2-5 November 1981. (Not available).

The electrolytical decomposition potentials of solid $LiI \cdot H_2O$ and of molten $LiI \cdot 2H_2O$, $LiBr \cdot 2H_2O$, and $LiCl \cdot 2H_2O$ have been determined by cyclic voltametry. Contrary to the melts the solid shows no sign of electrolysis of the water molecule. The usefulness of cyclic voltametry is discussed.

In-pile Corrosion Testing of Nb-containing Zr-alloys (Scanuk Alloys).

K. Rørbo, presented at the 11éme Réunion du Groupe de Travail "Corrosion Nucléaire" de la Fédération Européenne de la Corrosion, Erlangen, 10-11 December 1981. (Transcript available, 33 pp.).

As part of a collaborative programme between UK and the Scandinavian countries with the aim to develop zirconium alloys with better performance than Zircaloy-2 under BWR and PWR conditions, four Nb-containing (0,5-1% Nb) Zr-alloys (Scanuk alloys) were corrosion tested together with Zircaloy-2 in a corrosion test rig in the Danish experimental reactor DR 3.

The specimens were tested in-pile (fast flux $2 \cdot 10^{13}$ n/cm^2 sec.) and out-of-pile at 285°C in water with a medium and a high oxygen content (0,1 - 0,2 ppm and 3 ppm respectively).

The Scanuk alloys were in the post-transition state, prefollowing a quasilinear law, while Zr-2 still was in the transition state after a test period of 134 days. The specific weight gain of the Scanuk alloys was a factor of 3 to 5 higher than that of Zr-2. However, the hydrogen up-take in the Scanuk alloys was lower than in Zr-2. For all the alloys tested the weight gains at 0,1 - 0,2 ppm oxygen and at 3 ppm oxygen were statistically identical.

Corrosion Aspects of High-Level Waste Disposal in Salt Domes.
K. Rørbo, presented at Elsam/Elkrafts Symposium on Disposal of High-Level Waste, Copenhagen, 18-19 November 1981. (Transcript available, 37 pp. Proceedings to be published).

In the ELSAM/ELKRAFT waste management project it is planned that the high-level waste is glassified, encapsulated in canisters and finally deposited in a deep hole drilled in a salt dome. In the present report corrosion aspects of the canisters after deposition are discussed. The chemical environment will probably be a limited amount of brine coming from brine inclusions in the surrounding salt and moving up against the temperature gradient, the temperature at the canister surface being in the range of 100-150°C. The possible types of corrosion and the expected corrosion rates for a number of potential canister materials (mild steel, austenitic and ferritic stainless steels, Ni-base alloys, copper, titanium and a few combinations of materials) are discussed. Mild steel (possibly combined with an inner layer of copper or titanium) might possibly be an appropriate choice of material for the canister.

Erfaringer vedrørende industrielle anvendelser af højtemperaturlegeringer. (Experiences concerning Industrial Applications of High Temperature Alloys).
K. Rørbo, present at Herning-Messen, 9 September 1981. (Not available).

Typical metallurgical problems by the use of high temperature materials (structural instability, creep and creep rupture, high temperature corrosion etc.) are exemplified by a number of practical cases.

Højtemperaturlegeringer. (High Temperature Alloys).
K. Rørbo, presented at Dansk Forening for Materialografi's Novemberseminar, Kolding, 26-27 November 1981. (Not available).

Important high temperature material properties as creep resistance, shock resistance, thermal fatigue, structural stability, corrosion resistance (oxidation, carburization, sulfidation, nitriding) etc. are discussed and the most important groups of high temperature materials are mentioned. Some typical problems are exemplified by a number of practical cases.

Defect Accumulation During Irradiation in Fission and Fusion Reactor Environments.

B.N. Singh, presented at the Eidgenössisches Institut für Reaktorforschung, Würenlingen, 5 November 1981. (Not available).

A general framework of physical processes involved in defect accumulation and structural evolution will be outlined. The role of gas atoms in void nucleation will be considered. Some theoretical results on the effects of gas generation rate and gas concentration on void nucleation will be described. Finally, the significance of 600 MeV proton irradiation experiments will be discussed.

An Assessment of Void Nucleation by Gas Atoms During Irradiation.

B.N. Singh, and A.J.E. Foreman, presented at the 2nd Topical Meeting on Fusion Reactor Materials, Seattle, 9-12 August 1981. (To appear in J. Nucl. Mater.).

The main assumptions, limitations and predictions of current theories are summarized. The role of gas atoms in void nucleation is estimated. Using the "homogeneous" nucleation theory based on agglomeration of gas-vacancy clusters, the effect of helium generation rate and concentration on void density has been calculated; the concentration dependence is compared with experimental results.

Effects of Implanted Helium on Void Nucleation During HVEM Irradiation of Stainless Steel Containing Silicon.

B.N. Singh, T. Leffers, M.J. Makin, G.P. Walters and A.J.E. Foreman, presented at the 2nd Topical Meeting on Fusion Reactor Materials, Seattle, 9-12 August 1981. (To appear in J. Nucl. Mater.).

The combined effects of both silicon and helium on void nucleation in a high purity stainless steel have been studied during electron irradiation in a high voltage electron microscope in the temperature range 400-750°C. The nucleation of voids was not affected by silicon up to 0.5 wt%, either with or without 10 ppm helium. At higher silicon levels continuous nucleation occurred with a reduced maximum void density. The void density was increased by helium in all cases and up to 0.5% silicon showed a characteristic two stage temperature dependence, with activation energies of 0.5 and 1.0 eV, in contrast to the single stage in alloys without helium and in > 0.5% silicon materials with helium. The results are discussed in terms of two mechanisms; the binding of gas to silicon atom clusters and the segregation of silicon to void nuclei.

Effects of High Helium Production Rate on Microstructural Evolution in Aluminium During 600 MeV Proton Irradiation.
W.V. Green, S.L. Green, B.N. Singh and T. Leffers, presented at the 2nd Topical Meeting on Fusion Reactor Materials, Seattle, 9-12 August 1981. (To appear in J. Nucl. Mater.).

Samples of high purity-aluminium were irradiated at ~ 120°C with 600 MeV protons to 0.2, 0.6 and 2 dpa. Irradiation with 600 MeV protons produces displacement damage as well as helium, hydrogen and other impurities through spallation reactions. TEM on irradiated samples has shown that cavities are formed only in a relatively narrow band in the neighbourhood of the grain boundaries; the grain interior contained very few or no cavities. At 2 dpa, small cavities were observed also at the grain boundaries. Cavities with dual size distributions appeared at 0.6 and 2 dpa; the presence of large cavities strongly influences the nucleation of small cavities. Cavity denuded zones were observed along dislocation walls. It is suggested that the small cavities are formed by helium atoms whereas the large ones are nucleated by the residual gases.

Lagring af hydrogen i metaller. (Storage of Hydrogen in Metals).
A. Schrøder Pedersen, presented at the H.C. Ørsted Institute, Copenhagen, 17 September 1981. (Not available).

The physical chemistry of metal hydrogen systems was reviewed and illustrated by numerical examples. At the end of the talk some applications of present, practical interest were considered.

Fatigue Reliability under Random Loads.
R. Talreja, presented at a meeting in the Metals Society on Statistical Aspects of Fatigue and Fracture, London, 17 December 1981. (Not available).

The procedures for assessing fatigue reliability under deterministic loads were reviewed and the problems involved in extending these procedures to the case of random loads were discussed. The exact methods for estimating failure rates under random loads were described and the usefulness of approximate methods was discussed. An approximate method was proposed and its predictions were found in good agreement with the actual data.

A Probabilistic Fracture Mechanics Characterization of Impact Penetration Damage.

R. Talreja, poster presented at the 5th International Conference on Fracture, Cannes, 29 March - 3 April 1981. (Not available).

A procedure for estimating the reliability of an impact-damaged structure was proposed. The impact damage was modelled in terms of the crack geometry parameters and the residual strength was described by a 3-parameter Weibull distribution. The procedure was illustrated by using experimental strength data reported in literature and a good agreement between the predicted reliability estimates and the actual data was found.

Stiffness Changes Caused by Tensile Fatigue Damage in Fibrous Composites.

R. Talreja, presented at the 6th Conference on Composite Materials: Testing and Design, Phoenix, Arizona, 12-13 May 1981. (Not available).

Changes in the stiffness components of a unidirectional glass/polyester composite subjected to tensile fatigue were reported. The simultaneous changes in the longitudinal elastic modulus, the in-plane shear modulus and the major and the minor Poisson's ratios were discussed in terms of the underlying damage mechanisms.

Highly Defective Oxides.

O. Toft Sørensen, presented at a NATO Summer School on "Mass Transport in Solids", Lannion, France, 28 June - 11 July 1981. (Proceedings to be published).

Topics covered: Classification of nonstoichiometric oxides, formation and properties of defective oxides, Brouwer (Kröger/Vink) diagrams, thermodynamic properties, defect structure of oxygen deficient and metal deficient oxides.

Thermodynamics and Defect Structure of Highly Defective Oxides.

O. Toft Sørensen, presented at Massachusetts Institute of Technology, Cambridge, Massachusetts, 12 November 1981. (Not available).

Topics covered: General introduction to thermodynamic properties and defect structure formed in oxygen deficient nonstoichiometric oxides.

Magnesium for Hydrogen Energy.

B. Vigeholm, presented at the 38th World Conference on Magnesium, Houston, 10-13 May 1981. (Transcript available, 8 pp.).

A review of magnesium hydride research, application and perspectives in energy storage.

Metalhydrider og deres anvendelse i energiteknologien. (Metal Hydrides and Their Application in Energy Technology).

B. Vigeholm, presented to Ingeniørsammenslutningen, Vejle, 17 September 1981. (Not available).

A review was given on research, application and perspectives regarding the use of magnesium hydride in energy storage.

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